Manuscript Report No. 89-15

Evolution of limnological conditions in lakes of the Nelson and Rat-Burntwood river systems after Churchill River diversion and Lake Winnipeg regulation: I. An Overview.

By Ramsey, D.J., L. Livingston, I. Hagenson, and D.J. Green. 1989

Manitoba
Natural Resources
Fisheries

Evolution of Limnological Conditions in Lakes of the Nelson and Rat-Burntwood River Systems after Churchill River Diversion and Lake Winnipeg Regulation: I. An Overview.

Prepared by:

Douglas J. Ramsey

Agassiz North Associates
1214-B Chevrier Boulevard
Winnipeg, Manitoba
R3T 1Y3

In Collaboration With

Laureen Livingston
Ian Hagenson
and
David J. Green

Province of Manitoba
Department of Natural Resources
Fisheries Branch
1495 St. James Street
Winnipeg, Manitoba
R3H 0W9

March 1989

89-05889/

Ramsey, D. J., L. Livingston, I. Hagenson, and D. J. Green. 1989. Evolution of limnological conditions in lakes of the Nelson and Rat-Burntwood river systems after Churchill River diversion and Lake Winnipeg regulation: I. An Overview. Manitoba Department of Natural Resources, Fisheries Branch MS Report No. 89-15, 89 pp.

ABSTRACT

The Fisheries Branch of the Manitoba Department of Natural Resources initiated studies of the limnology of Rat and Threepoint lakes on the Churchill River diversion and of Cross, Sipiwesk, Split, and Stephens lakes on the Nelson River in 1985. The hydrologic regimes of these lakes have been altered by Lake Winnipeg Regulation or Churchill River diversion or by both developments. This report summarizes the water quality data collected through 1987 and the phytoplankton and zooplankton data collected through 1988. These data are compared to pre-development data reported by the Lake Winnipeg, Churchill, and Nelson Rivers Study Board to provide an overview of the changes in water quality and in the phytoplankton and zooplankton communities which have occurred in the lakes following hydroelectric development. The effects of changes in analytical methodology which may confound the interpretation also are considered. Limitations of the pre- and post-development data which restrict the scope of the report conculsions are identified and types of new or existing data collection and analysis which could minimize or eliminate these restrictions are suggested.

Table of Contents

	Page
Contents	i
List of Tables	iii
List of Figures	v
1.0 Introduction	1
2.0 Changes in Analytical Methods	3
3.0 Description of the Study Lakes and Sampling Locations	5
3.1 Rat-Burntwood Lakes	6
3.1.1 Rat Lake	6
3.1.2 Threepoint Lake	6
3.2 Upper Nelson Lakes	6
3.2.1 Cross Lake	6
3.2.2 Sipiwesk Lake	10
3.3 Middle Nelson Lakes	10
3.3.1 Split Lake	10
3.3.2 Stephens Lake	13
4.0 Limnological Changes in the Rat-Burntwood Lakes	16
4.1 Water Chemistry	16
4.1.1 Rat Lake	16
4.1.1.1 Spatial and Annual Variation	16
4.1.1.2 Comparison with 1973	16
4.1.2 Threepoint Lake	21
4.1.2.1 Spatial and Annual Variation	21
4.1.2.2 Comparison with 1972-73	24
4.2 Phytoplankton Composition Biomass and Periodicity	27
4.2.1 Spatial and Annual Variation	27
4.2.2 Rat Lake - Comparison with 1973	32
4.3 Zooplankton Composition Biomass and Periodicity	34
4.3.1 Rat Lake	34
4.3.2 Threepoint Lake	34

	Page
5.0 Limnological Changes in the Upper Nelson Lakes	39
5.1 Cross Lake	39
5.1.1 Water Quality	39
5.1.1.1 Spatial and Annual Variation	39
5.1.1.2 Mainstem Station - Comparison with 1972-73	42
5.1.2 Phytoplankton Composition Biomass and Periodicity	44
5.1.2.1 Spatial and Annual Variation	44
5.1.2.2 Mainstem Station - Comparison with 1973	47
5.1.3 Zooplankton Composition Biomass and Periodicity	49
5.2 Sipiwesk Lake	52
5.2.1 Water Quality	52
5.2.1.1 Spatial and Annual Variation	52
5.2.1.2 Comparison with 1972-73	52
5.2.2 Phytoplankton Composition Biomass and Periodicity	56
5.2.2.1 Spatial and Annual Variation	56
5.2.2.2 Comparison with 1972-73	60
5.2.3 Zooplankton Composition Biomass and Periodicity	60
6.0 Limnological Changes in the Middle Nelson Lakes	64
6.1 Split Lake	64
6.1.1 Water Quality	64
6.1.1.1 Spatial and Annual Variability	64
6.1.1.2 Mainstem Station - Comparison with 1972-73	69
6.1.2 Phytoplankton Composition Biomass and Periodicity	70
6.1.2.1 Spatial and Annual Variation	70
6.1.2.2 Comparison with 1972-73	73
6.1.3 Zooplankton Composition Biomass and Periodicity	73
6.2 Stephens Lake	76
6.2.1 Water Quality	76
6.2.1.1 Moose Lake Area - Comparison with 1972-73	76
6.2.1.2 Mainstem Stations - Comparison with 1972-73	79
6.2.2 Phytoplankton Composition Biomass and Periodicity	81
6.2.2.1 Spatial and Annual Variation	81
6.2.2.2 Comparison with 1972-73	81
6.2.3 Zooplankton Composition Biomass and Periodicity	84
7.0 Recommendations for Future Studies	88
8.0 References	89

List of Tables

		Page
1.	Comparison of seasonal mean nutrient concentrations in Rat Lake before and after Churchill River diversion.	17
2.	Comparison of seasonal mean pH and concentrations of anions, cations, and metals in Rat Lake before and after Churchill River diversion.	18
3.	Comparison of seasonal mean transparency, turbidity, dissolved and suspended solids concentrations, and colour in Rat Lake before and after Churchill River diversion.	19
4.	Comparison of seasonal mean transparency, turbidity, dissolved and suspended solids concentrations, and colour in Threepoint Lake before and after Churchill River diversion.	22
5.	Comparison of seasonal mean pH and concentrations of anions, cations, and metals in Threepoint Lake before and after Churchill River diversion.	23
6.	Comparison of seasonal mean nutrient concentrations in Threepoint Lake before and after Churchill River diversion.	25
7.	Comparison of seasonal mean nutrient concentrations in Cross Lake before and after Lake Winnipeg regulation.	40
8.	Comparison of seasonal mean pH and concentrations of anions, cations, and metals in Cross Lake before and after Lake Winnipeg regulation.	41
9.	Comparison of seasonal mean transparency, turbidity, dissolved and suspended solids concentrations, and colour in Cross Lake before and after Lake Winnipeg regulation.	43
10.	Comparison of seasonal mean nutrient concentrations in Sipiwesk Lake before and after Lake Winnipeg regulation.	53
11.	Comparison of seasonal mean pH and concentrations of anions, cations, and metals in Sipiwesk Lake before and after Lake Winnipeg regulation.	54
12.	Comparison of seasonal mean transparency, turbidity, dissolved and suspended solids concentrations, and colour in Sipiwesk Lake before and after Lake Winnipeg regulation.	55
13.	Comparison of seasonal mean pH and concentrations of anions, cations, and metals in Split Lake before and after Churchill River diversion and Lake Winnipeg regulation.	66

List of Tables, continued

	Page
14. Comparison of seasonal mean nutrient concentrations in Split Lake before and after Churchill River diversion and Lake Winnipeg regulation.	67
15. Comparison of seasonal mean transparency, turbidity, dissolved and suspended solids concentrations, and colour in Split Lake before and after Churchill River diversion and Lake Winnipeg regulation.	68
16. Comparison of seasonal mean transparency, turbidity, dissolved and suspended solids concentrations, and colour in Stephens Lake before and after Churchill River diversion and Lake Winnipeg regulation.	77
17. Comparison of seasonal mean nutrient concentrations in Stephens Lake before and after Churchill River diversion and Lake Winnipeg regulation.	78
18. Comparison of seasonal mean pH and concentrations of anions, cations, and metals in Stephens Lake before and after Churchill River diversion and Lake Winnipeg regulation.	80

List of Figures

	Page
1. Location of the study lakes.	7
2. Limnological sampling sites on Rat Lake.	8
3. Limnological sampling sites on Threepoint Lake.	9
4. Limnological sampling sites on Cross Lake.	11
5. Limnological sampling sites on Sipiwesk Lake.	12
6. Limnological sampling sites on Split Lake.	14
7. Limnological sampling sites on Stephens Lake.	15
8. Algal biomass and taxonomic composition during the summer of 1987 in Rat Lake.	28
9. Algal biomass and taxonomic composition during the summer of 1988 in Rat Lake.	29
10. Algal biomass and taxonomic composition during the summer of 1987 in Threepoint Lake.	30
11. Algal biomass and taxonomic composition during the summer of 1988 in Threepoint Lake.	31
12. Algal biomass and taxonomic composition during the summer of 1973 in Rat Lake and other lakes on the Rat and Burntwood rivers. From Hecky and Harper (1974).	33
13. Distribution of zooplankton biomass among the major taxonomic groups during the summer of 1987 in Rat Lake.	35
14. Distribution of zooplankton biomass among the major taxonomic groups during the summer of 1988 in Rat Lake.	36
15. Distribution of zooplankton biomass among the major taxonomic groups during the summer of 1987 in Threepoint Lake.	37
16. Distribution of zooplankton biomass among the major taxonomic groups during the summer of 1988 in Threepoint Lake.	38
17. Algal biomass and taxonomic composition during the summer of 1987 in Cross Lake.	45
18. Algal biomass and taxonomic composition during the summer of 1988 in Cross Lake.	46
19. Algal biomass and taxonomic composition during the summer of 1973 in lakes on the Nelson River. From Hecky and Harper (1974).	48

List of Figures, continued

	Page
20. Distribution of zooplankton biomass among the major taxonomic groups during the summer of 1987 in Cross Lake.	50
21. Distribution of zooplankton biomass among the major taxonomic groups during the summer of 1988 in Cross Lake.	51
22. Algal biomass and taxonomic composition during the summer of 1987 in Sipiwesk Lake.	57
23. Algal biomass and taxonomic composition during the summer of 1988 in Sipiwesk Lake.	58
24. Algal biomass and taxonomic composition during the summer of 1972 in lakes on the Nelson River. From Hecky and Harper (1974).	61
25. Distribution of zooplankton biomass among the major taxonomic groups during the summer of 1987 in Sipiwesk Lake.	62
26. Distribution of zooplankton biomass among the major taxonomic groups during the summer of 1988 in Sipiwesk Lake.	63
27. Algal biomass and taxonomic composition during the summer of 1987 in Split Lake.	71
28. Algal biomass and taxonomic composition during the summer of 1988 in Split Lake.	72
29. Distribution of zooplankton biomass among the major taxonomic groups during the summer of 1987 in Split Lake.	74
30. Distribution of zooplankton biomass among the major taxonomic groups during the summer of 1988 in Split Lake.	75
31. Algal biomass and taxonomic composition during the summer of 1987 in Stephens Lake.	82
32. Algal biomass and taxonomic composition during the summer of 1988 in Stephens Lake.	83
33. Distribution of zooplankton biomass among the major taxonomic groups during the summer of 1987 in Stephens Lake.	85
34. Distribution of zooplankton biomass among the major taxonomic groups during the summer of 1988 in Stephens Lake.	86

1.0 Introduction

The Fisheries Branch of the Manitoba Department of Natural Resources in 1985 initiated studies of the limnology of several lakes on the Rat, Burntwood, and Nelson rivers in which the hydrologic regimes have been changed by Lake Winnipeg regulation and/or Churchill River diversion. The results of these studies, when compared with pre-development data such as that collected by the Lake Winnipeg, Churchill, and Nelson Rivers (LWCNR) Study Board and others, may indicate the nature and magnitude of changes in water quality and in the composition and biomass of the phytoplankton and zooplankton communities in these lakes which have occurred as a result of hydroelectric development. The ultimate goal of these studies is to relate changes in water quality or in the primary or secondary producers to changes in the composition and productivity of fish communities in the lakes and to adverse effects on the communities signatory to the Northern Flood Agreement. Some phytoplankton data have already been reported (Livingstone 1988) and other data reports are in preparation. The purpose of this report is to summarize the water quality, phytoplankton, and zooplankton data collected by the Fisheries Branch to date and, through comparisons with information presented in the LWCNR reports, to identify differences between present and pre-development conditions which may be related to Churchill River diversion and Lake Winnipeg regulation.

For a change in a given parameter to be attributed to the hydroelectric developments, it must be demonstrated that it is not due to some change in analytical or sampling methodology, variation in laboratory performance, or to natural variability. Changes in analytical methodology are described in Section 2.0. The effect of variation in laboratory performance over time using the same methods could not be considered, however. Interlaboratory comparisons for quality control purposes are a relatively recent innovation and were not

done in the early 1970's. The laboratories which have performed the analyses have long-term data from various locations which might be suitable for evaluation of this source of variation in subsequent reports.

The effect of natural variation was not considered in this report primarily because no reference or control site was included in either the LWCNR studies or in the current studies conducted by the Fisheries Branch. Indeed no single location would be a suitable reference site for all parts of the system. However, it should be possible to derive some estimate of the contribution of natural variation to the differences or changes documented in this report through the review of other studies which have been conducted in the system over the past 16 years.

The extent and conclusions of this retrospective analysis also are limited by the quantity and quality of the pre-development data which are available. For example, pre-development zooplankton data are available only for Rat Lake (Patalas and Salki 1974) and these data differ significantly from the type of information gathered in the present study. Whereas the previous study emphasized the definition of community composition with identification to the species level but without calculation of biomass, the present study concentrated on the estimation of standing biomass with identification only to the level of genus. At present, the pre-and post-development data sets for Rat Lake are not directly comparable. Organisms in the samples collected by DNR will have to be identified to species and the data of Patalas and Salki (1974) must be converted to biomass. Both can be done but the work is outside the scope of this report. Consequently, only a general description of recent spatial and interannual variation in zooplankton standing stocks in the study lakes is included in this report.

The depth of interpretation in this report also is limited by the data

which were available at the time of writing. Phytoplankton data are available for 1987 and 1988 while water chemistry and physical data are available only for 1985, 1986, and 1987. Consequently, no evaluation of the cause of interannual variation in the phytoplankton based on nutrient availability or changes in the light regime could be included in the report.

With these limitations, this document clearly does not represent a definitive statement of the effects of Churchill River diversion and Lake Winnipeg regulation on the water quality, phytoplankton, and zooplankton of the study lakes. Instead, it was prepared as an overview of differences in current limnological conditions compared with conditions described in the LWCNR study reports. In most cases, the differences cannot be specifically attributed to hydro development. However, mechanisms to explain the differences are suggested where possible and in many cases the hydro developments are implicated. Subsequent reports will evaluate these hypotheses as well as investigate the significance of sources of change or variation other than the changes in hydrologic regime imposed by the developments.

2.0 Changes in Analytical Methods

Several analytical methods have changed since the pre-development studies. The efficiency of total dissolved nitrogen determinations made at the Freshwater Institute laboratory has improved since 1974 (M. Stainton, Freshwater Institute, pers. comm.). More detailed investigations than were possible for this report would be necessary to quantify this increase in efficiency. Consequently, any increases which have occurred since development may reflect the change in this method. More importantly, the change would also tend reduce the magnitude of any decreases in TDN. Any decreases in TDN will in fact be greater than that indicated in this report.

The method for determination of total iron used at the Ward Lab also has changed since the pre-development studies (E. Sorba, Ward Lab, pers. comm.). From 1971-75, the Technicon method was used while atomic absorption spectrometry has been used since that time. Although the majority of cross-comparison samples analysed at the time of methods change indicated the methods had comparable performance, the values produced by the Technicon method were unaccountably low (e.g., 0.1 compared with 0.6 mg L^{-1} by AA) on 6 of the 50 cross-check samples. The occurrence of higher iron concentrations at all locations in 1986-87 compared with 1972-73 and the similarity of the magnitude of the differences with that of the anomaly found in the cross-comparison indicates that the apparent increases in iron since development may instead be an artifact of the change in analytical methods.

Other analytical procedures at the Ward Lab which have changed are colour and turbidity. A quality control procedure for colour determinations has been introduced which ensures that the colour comparison disks are changed at regular intervals. A comparison between "old" and "new" disks made in 1974 indicated that colour values determined with old disks could differ from values obtained with new disks by 5-10 units. All analyses in 1972-73 were made with old disks. Therefore, any change in colour of less than 10 units since 1972-73 is considered in this report to be a result of the change in laboratory procedure.

The change in the turbidity analysis procedure is a change in the type of turbidimeter used. In 1972-74, a transmissive type of turbidimeter was used compared with an optical backscatter turbidimeter in the current study. The backscatter instrument is more sensitive and increases precision thereby reducing the variability of measurements but not necessarily increasing accuracy.

No other changes in analytical methods have been made at either the DFO or the Ward laboratories.

The Utermohl technique as modified by Nauwerck (1963) was used for analysis of the phytoplankton samples both in this study and in the the LWCNR study although the technicians were different. R. Harper analysed the samples for the LWCNR study while D. Findlay analysed the samples for the current study. The effect of these different analysts on the estimates of phytoplankton standing stocks is not known.

3.0 Description of the Study Lakes and Sampling Locations

Six lakes are monitored in the program; Cross Lake and Sipiwesk Lake on the upper Nelson River, Rat Lake and Threepoint Lake on the Churchill River Diversion, and Split Lake and Stephens Lake on the middle Nelson River (Figure 1). Three sampling stations have been established in each lake with one station located near the major inlet and outlet. The location of the third station was more variable, in some lakes it was located centrally (e.g., Rat Lake) but in other lakes it ws located in a backwater (e.g., Stephens Lake). Where possible, stations have been located near those sampled in the LWCNR studies. Outlined below are the histories of regulation or diversion of the study lakes along with descriptions of the locations of current sampling stations and comparisons with locations of sampling sites for which pre-development data are available. In this study, pre-development refers specifically to the period before lake Winnipeg regulation and Churchill River diversion. The regulation structures at Kelsey and Kettle were already in operation when the LWCNR studies were conducted.

3.1 Rat-Burntwood Lakes

3.1.1 Rat Lake

Rat Lake is located on the Rat River above the Notigi control structure (Figure 1). The control structure became operational in 1974 and the mean lake level rose 10.1m in the following 3 years (Newbury et al. 1974). Lake area increased 108% due to flooding (Green 1986). Station 1, located in the centre of the northern basin of lake, and station 3, in the southern basin, are directly influenced by the flow of the Churchill River diversion (Figure 2). Station 1 corresponds to Station A sampled in the LWCNR study (Cleugh 1974). Station 2 is off the main diversion flow in the central basin of the lake and corresponds to Station B in the LWCNR study (Figure 2; Cleugh 1974).

3.1.2 Threepoint Lake

Threepoint Lake is situated at the confluence of the Rat and Burntwood rivers below the Notigi control structure. Lake area increased 47% due to flooding (Green 1986). Station 1 is located in the northern area of the lake near the inflow from the Footprint River (Figure 3). Station 2 is located in the central basin of the lake and is influenced by flows from both the Churchill River diversion and the Burntwood River (Figure 3). Station 3 is located in the eastern basin of the lake near the outflow (Figure 3).

3.2 Upper Nelson Lakes

3.2.1 Cross Lake

Cross Lake is located on the Upper Nelson River with levels regulated since June 1976 by the generating station at Jenpeg (Figure 1). The seasonal water level regime in the lake has been reversed as a result of this regulation and levels are now lowest in summer and highest in winter. Sampling station 1

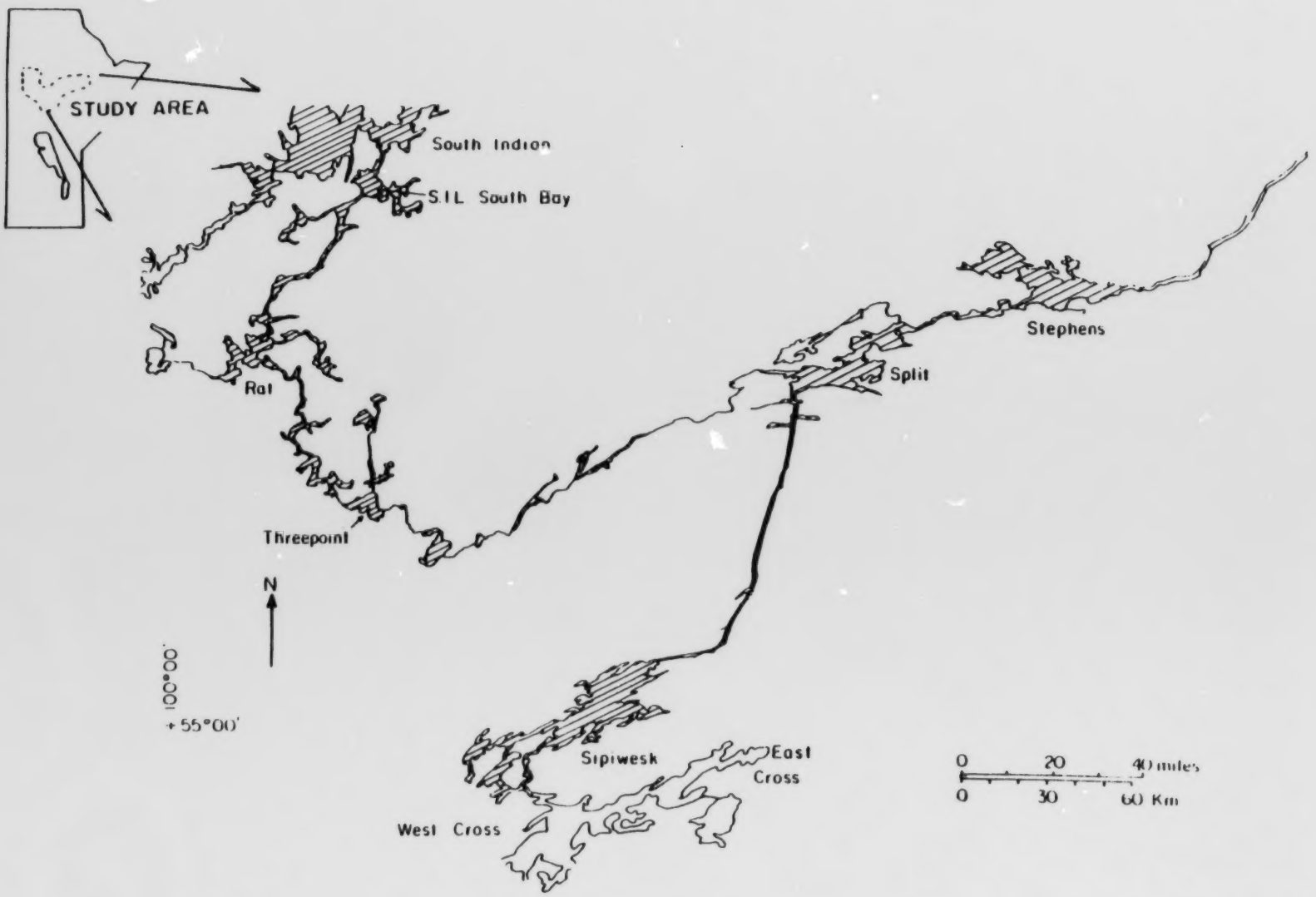

Figure 1. Location of the study lakes.

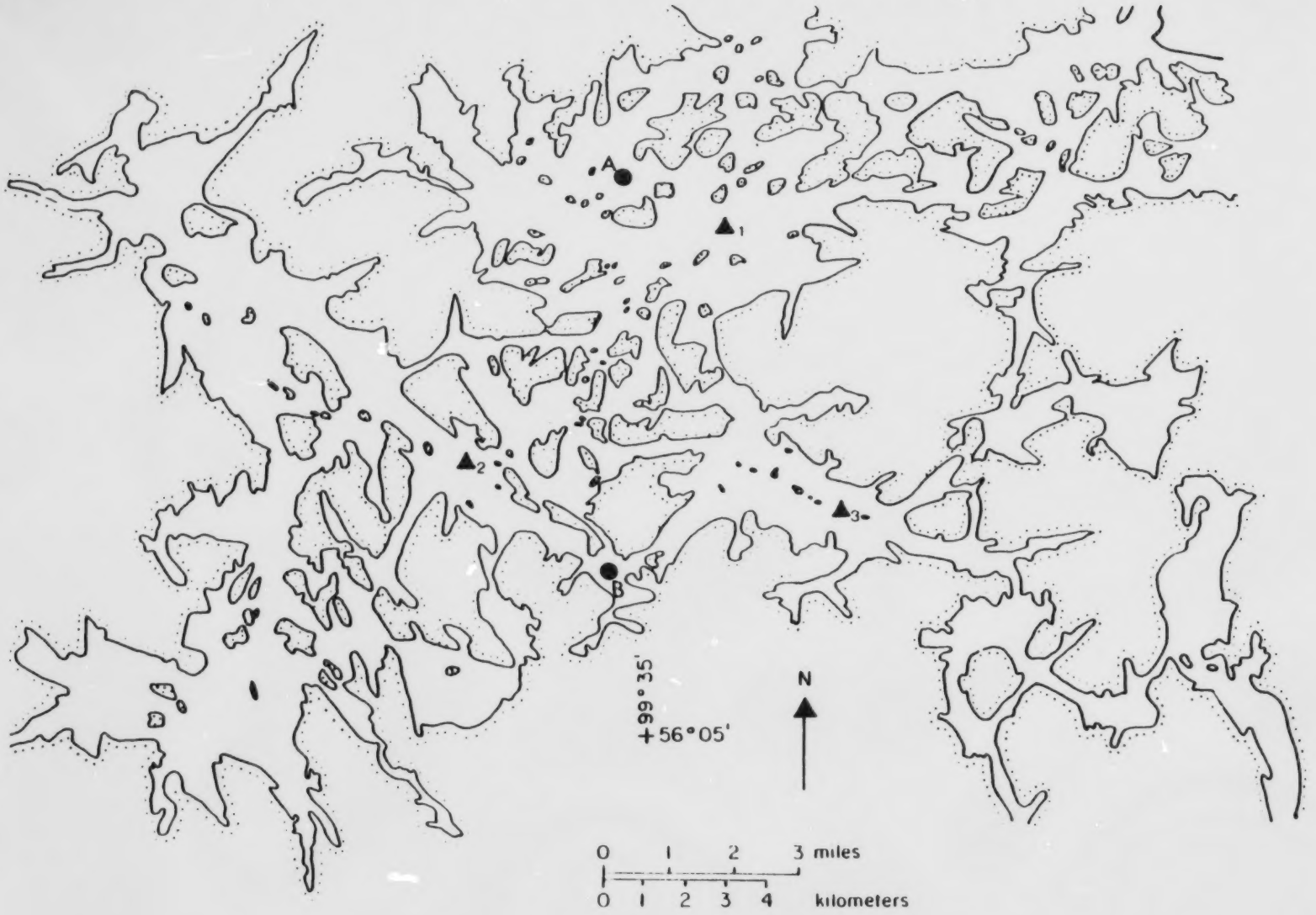

Figure 2. Location of sampling stations on Rat Lake (▲) and approximate location of LWCNR study sites (●).

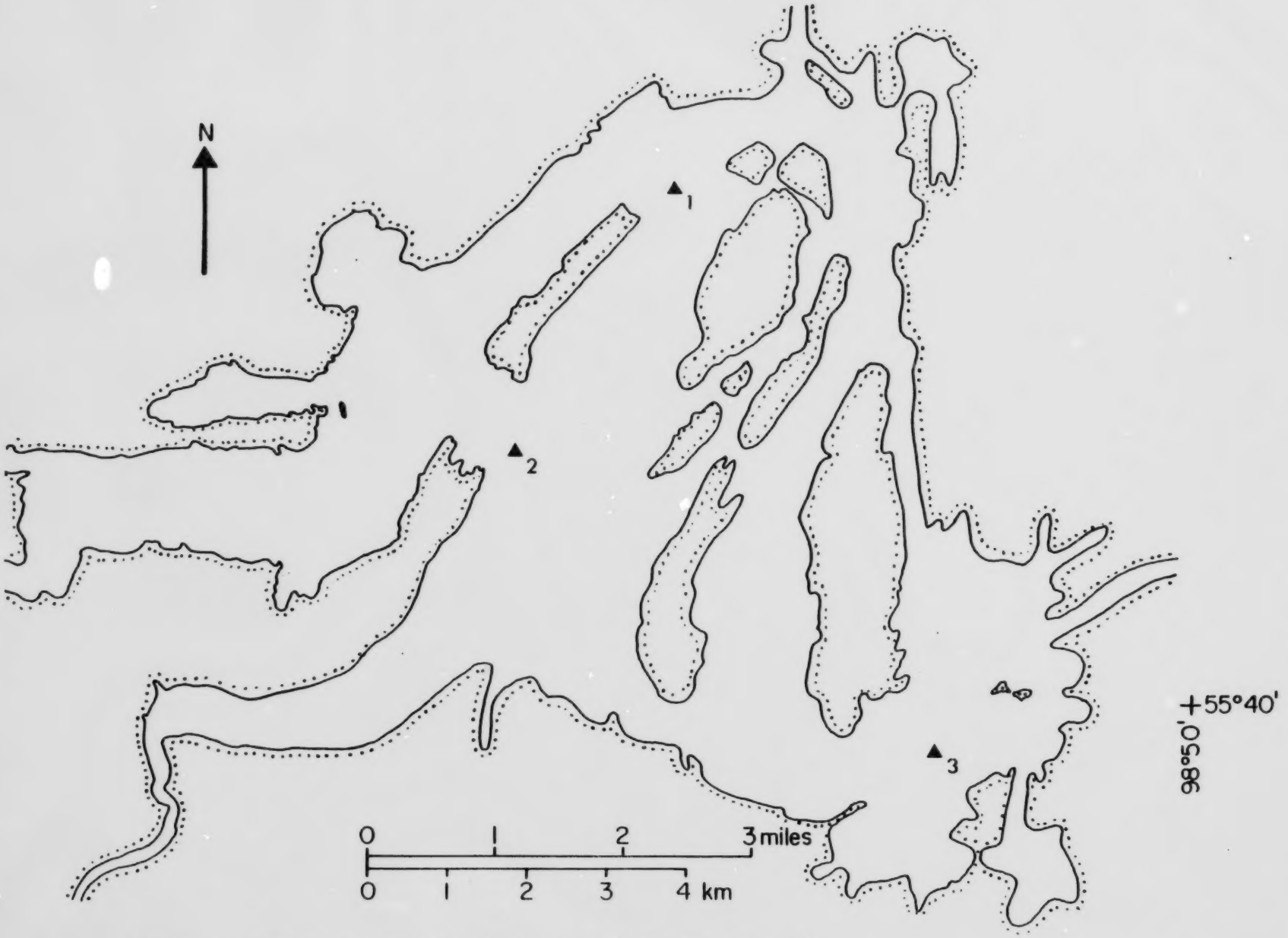

Figure 3. Location of sampling stations on Threepoint Lake (▲).

is located in the Sagatawak basin of the lake and is directly influenced by the flow of the Nelson River (Figure 4). This station most closely corresponds to station 240 in the LWCNR study, which was located at the lake outflow (Cleugh 1974). Station 2 is in the Middle Basin of West Cross Lake and station 3 is in the central basin of East Cross Lake (Figure 4). Both stations 2 and 3 can be considered backwater stations relative to station 1.

3.2.2 Sipiwesk Lake

Sipiwesk Lake was flooded by the Kelsey Generating Station located on the Nelson River above Split Lake (Figure 1). Lake levels rose approximately 3m between 1960 and 1965 (Water Survey of Canada 1960-65) and lake area increased approximately 20% (D. Windsor, Manitoba Hydro, pers. comm.). The water level regime in Sipiwesk Lake also has been affected by the operation of the Jenpeg control structure. Water levels are now lower in summer than in winter. Station 1 is located in Area A (Mud Bay), remote from the main flow of the Nelson River (Figure 5). There is no corresponding pre-development station. Stations 2 and 3 are located centrally in Areas B and C, respectively, and both are directly influenced by Nelson River flows (Figure 5). Station 3 corresponds most closely to station 1' in the LWCNR study, which was located at the outlet of Sipiwesk Lake (Cleugh 1974).

3.3 Middle Nelson Lakes

3.3.1 Split Lake

Split Lake is situated on the middle reach of the Nelson River, at the confluence with the Burntwood River (Churchill River diversion; Figure 1). the mean water level of Split Lake has increased approximately 1m since the diversion was placed in operation. Sampling station 1 is located in the

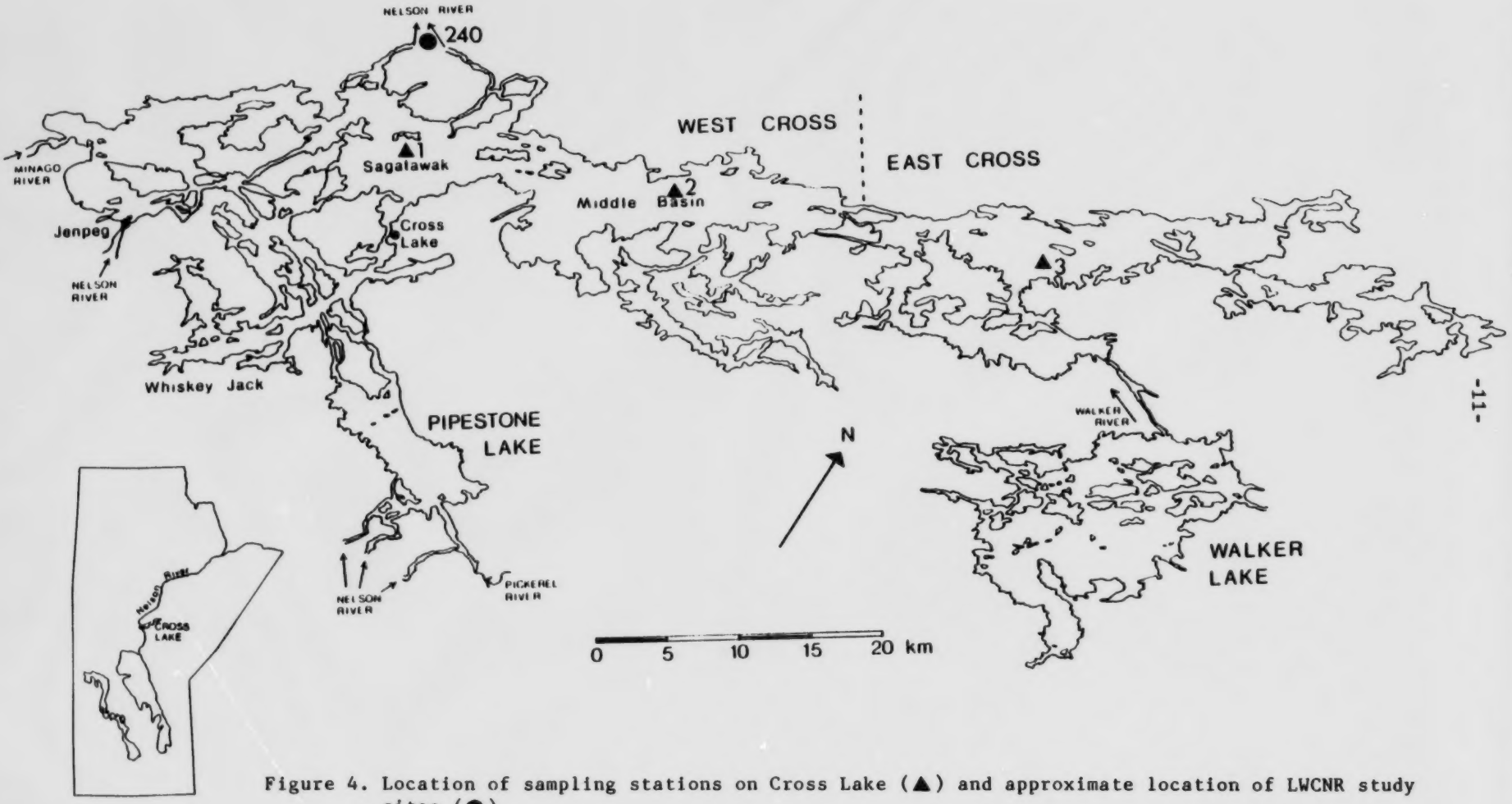

Figure 4. Location of sampling stations on Cross Lake (▲) and approximate location of LWCNR study sites (●).

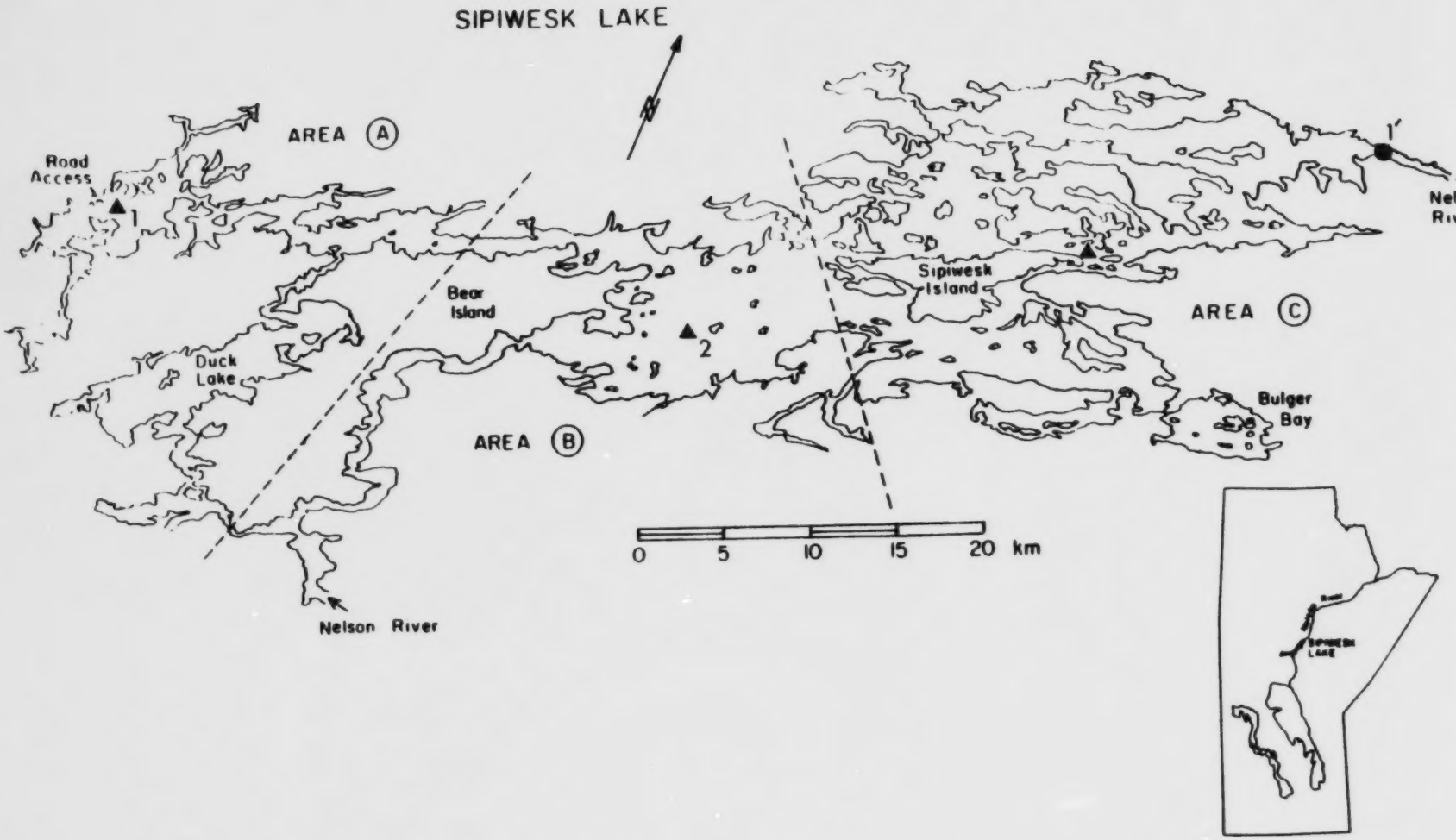

Figure 5. Location of sampling stations on Sipiwesk Lake (▲) and approximate location of LWCNR study sites (●).

northern, outflow, basin of the lake near the community of Split Lake. This station most closely corresponds to station 3 in the LWCNR study (Cleugh 1974). Station 2 is located in the eastern basin which receives flow from the Aiken River. There is no corresponding pre-development station. Station 3 is located at the western end of the lake near the inflow of the Burntwood River (Churchill River diversion). Station 4, sampled for chemistry only, is in the plumes of both the Nelson and Burntwood rivers (Figure 6).

3.3.2 Stephens Lake

Stephens Lake was formed in 1970 behind the Kettle Dam. Station 1 is located in a backflooded area in the northeastern part of the lake in the area of Moose Lake which was inundated by the reservoir (Figure 7). This location corresponds to Station 4 in the LWCNR study (Cleugh 1974). Stations 2 and 3 are located on the main-stem of the Nelson River; station 2 immediately below the inflow and station 3 above the outflow at the Kettle Generating Station (Figure 7). Station 3 corresponds to station 4' in the LWCNR study (Cleugh 1974).

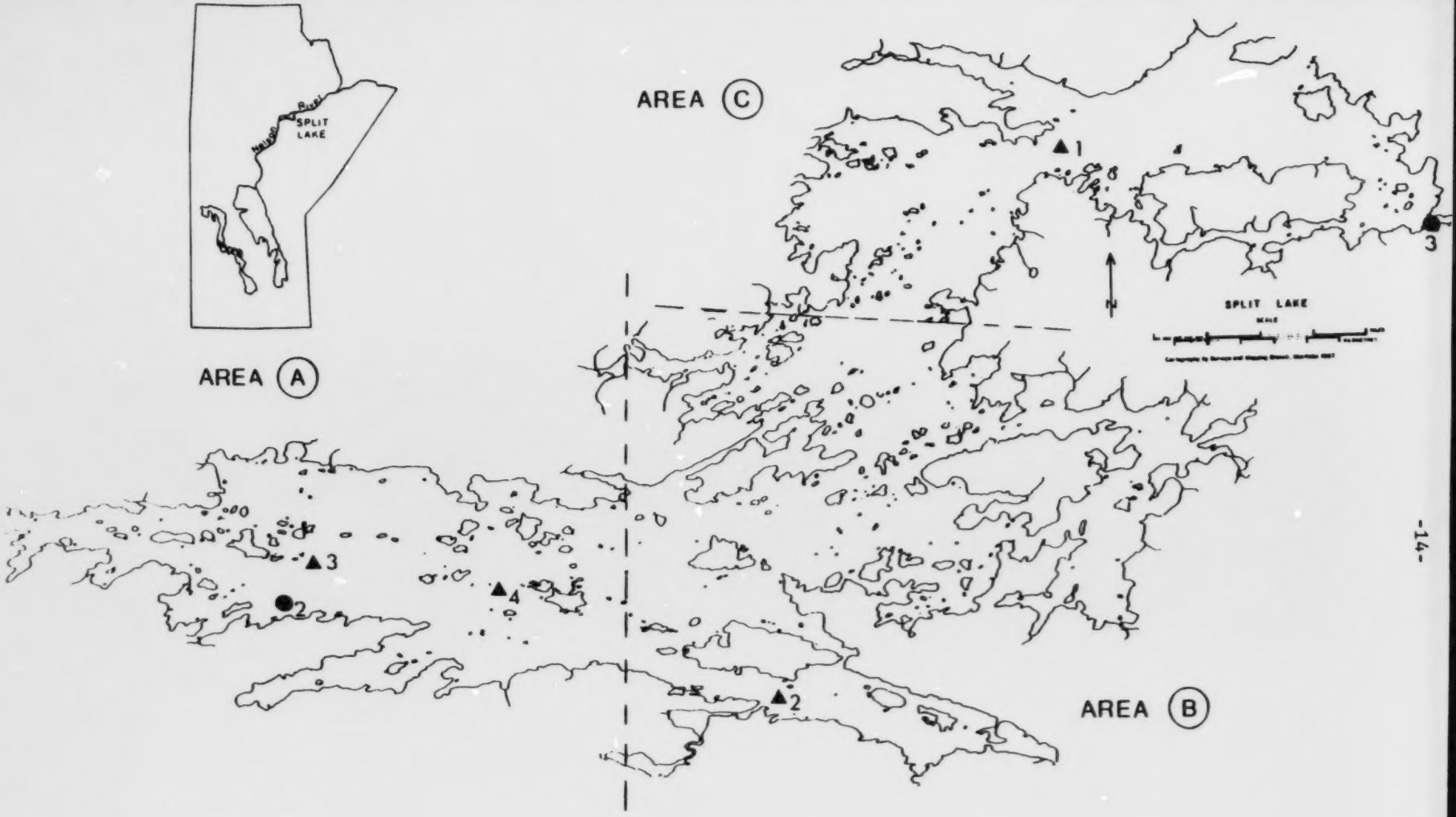

Figure 6. Location of sampling stations on Split Lake (▲) and approximate location of LWCNR study sites (●).

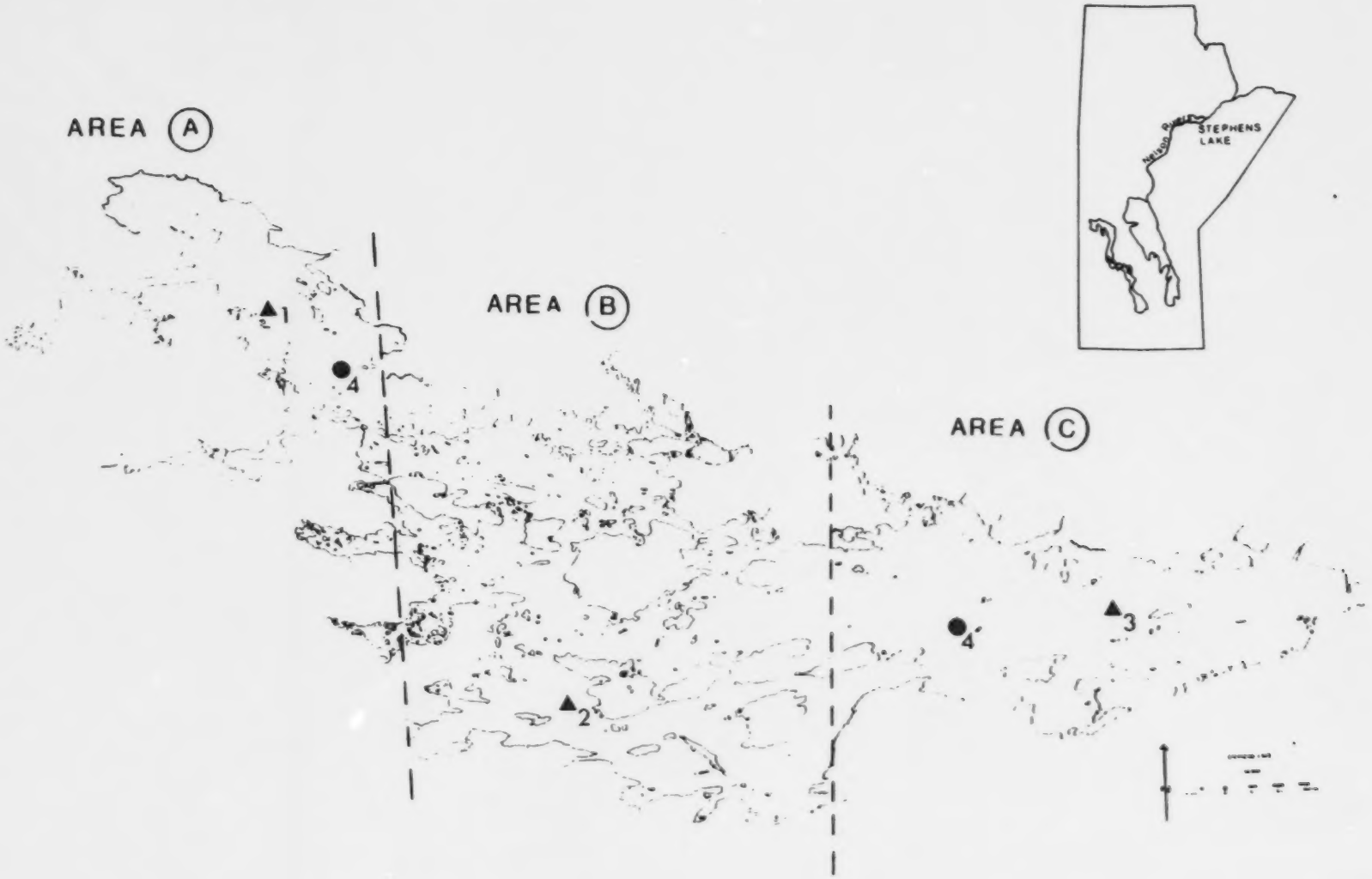

Figure 7. Location of sampling stations on Stephens Lake (▲) and approximate location of LWCNR study sites (●).

4.0 Limnological Changes in the Rat-Burntwood Lakes

4.1 Water Chemistry

4.1.1 Rat Lake

4.1.1.1 Spatial and Annual Variation

In general, there was little variation in water quality either among the three stations or between years in Rat Lake although transparency was about 10% higher in the backwater (station 2) than at the mainstem stations in both years (Tables 1,2, and 3). However, one major exception to this trend was NO_3-N which was much higher at station 2, the backwater station, than at the other stations in 1987 (Table 1). Otherwise, nutrient concentrations at station 2 were not characteristically different from the main-stem stations. Accompanying the higher NO_3-N levels at station 2 in 1987 was a 17% higher mean sodium concentration, and a 50% lower mean turbidity than at the mainstem stations (Tables 2 and 3). This lower turbidity at station 2 in 1987 was the combined result of higher levels on the mainstem and lower levels at station 2.

4.1.1.2 Comparison with 1973

There have been major changes in water quality in Rat Lake since the pre-development studies in 1973. Concentrations of all major nutrients, both in the dissolved and in the suspended fractions, are now lower (N parameters by 60-92%, P parameters by 21-70%, and C parameters by 24-49%; Table 1). No consistent pattern of change was noted in the anions and cations; some have increased, others have decreased, and some are unchanged; Table 2). Water transparency has decreased at the mainstem stations but concentrations of dissolved and suspended solids are unchanged (Table 3). The changes in specific parameters are detailed below.

Table 1. Comparison of seasonal mean nutrient concentrations in Rat Lake before and after Churchill River diversion.

Station		1973	1986 1	1986 2	1986 3	1987 1	1987 2	1987 3
NO_3-N	(ug L^{-1})	12	4	3	2	1	12	2
NO_3^2-N			<1	<1	<1	<1	<1	<1
NH_3^2-N			20	20	23	24	24	24
TDN		478	290	290	283	280	294	276
Susp N		257	54	59	55	59	67	59
TDP	(ug L^{-1})	17	18	16	17	12	12	11
Susp P		14	9	10	9	10	12	11
DIC	(umole L^{-1})	1204	817	820	783	915	941	906
DOC	(umole L^{-1})	848	567	590	577	572	586	568
Susp C	(ug L^{-1})	793	400	411	410	438	446	422
SrSi	(mg L^{-1})	1.55				0.87	0.91	0.88

Data sources
1973 Cleugh (1974), June 14 to September 24
1986 this study, June 9 to August 20
1987 this study, May 14 to August 31

Table 2. Comparison of seasonal mean pH and concentrations (mg L^{-1}) of anions, cations, and metals in Rat Lake before and after Churchill River diversion.

Station	1973	1986 1	1986 2	1986 3	1987 1	1987 2	1987 3
Anions							
Cl^-	1.2	<2	<2	<2	1.3	1.0	1.0
SO_4^{2-}	3.9	2.7	2.6	2.4	2.5	2.8	2.5
Cations							
Ca^{2+}	15.5	12.4	12.7	12.3	11.4	11.8	11.8
Mg^{2+}	4.15	4.06	4.21	4.11	4.05	4.15	4.08
Na^+	1.91	2.46	2.49	2.54	2.87	3.32	2.80
K^+	0.93	<5	<5	<5	1.09	1.09	1.08
pH							
lab	7.8	7.82	7.75	7.82	7.77	7.72	7.76
field		7.4	7.4	7.3	7.5	7.4	7.4
Metals							
Fe	0.09	0.17	0.23	0.25	0.26	0.24	0.29
As					<0.001	<0.001	<0.001
Cd					<0.001	<0.001	<0.001
Cu					<0.01	<0.01	<0.01
Zn					<0.01	<0.01	<0.01
Pb					<0.005	<0.005	<0.005
Ni					<0.005	<0.005	<0.005
Mn	0.09				<0.02	<0.02	<0.02

Data sources
1973 Cleugh (1974), June 14 to September 24
1986 this study, June 9 to August 20
1987 this study, May 14 to August 31

Table 3. Comparison of seasonal mean transparency, turbidity, dissolved and suspended solids concentrations, and colour in Rat Lake before and after Churchill River diversion.

Station	1973	1986 1	1986 2	1986 3	1987 1	1987 2	1987 3
Secchi (m)	1.3	0.97	1.10	1.03	0.89	0.94	0.83
Turbidity (NTU)		5.0	5.2	4.7	7.1	3.8	8.1
TR (mg L^{-1})					85.0	86.5	92.0
NFR	4				<5	<5	<5
TDS	85	68.7	78.7	82.0	96.0	84.2	88.0
Conductivity (uS cm^{-1})							
Lab (Ward)		98	100	98	98	103	100
Field	118	101	106	105	106	108	108
Calculated					108	111	108
Lab (DFO)					96	100	98
Colour (true)		13.3	13.3	11.7	14.0	11.0	15.0

Data sources
1973 Cleugh (1974), June 14 to September 24
1986 this study, June 9 to August 20
1987 this study, May 14 to August 31

Nitrate-nitrogen concentrations were lower, by 67-92%, at all stations in 1986 than in 1973 (Table 1). Concentrations at the mainstem stations were as low or lower still in 1987. Total dissolved nitrogen concentrations averaged 40% lower than the pre-impoundment concentration in both 1986 and 1987. Suspended nitrogen concentrations averaged about 77% lower than pre-impoundment concentrations in both years of study. Total dissolved phosphorus concentrations in 1986 were about the same as prior to impoundment but concentrations in 1987 were 30% lower than the pre-impoundment concentrations. Suspended phosphorus concentrations were about 33% lower than the pre-impoundment level in 1986 and were about 21% lower in 1987. Dissolved inorganic carbon concentrations averaged 33% lower in 1986 and 24% lower in 1987. Dissolved organic carbon concentrations averaged about 32% lower in both 1986 and 1987 than in 1973. Suspended carbon concentrations were 49% lower in 1986 and 45% lower in 1987. Silica concentrations averaged 57% lower in 1987 than in 1973.

Chloride concentrations were the same in 1986 and 1987 as in 1973 (Table 2). Sulfate concentrations averaged 33% lower in 1986 and 1987 than prior to impoundment. Calcium concentrations were somewhat lower in both years (20% in 1986 and 25% in 1987) than in 1973. Magnesium concentrations were the same in both 1986 and 1987 as in 1973. Sodium concentrations averaged 31% higher in 1986 and 57% higher in 1987 than in 1973. The limit of detection for potassium analyses used in 1986 was not sufficiently sensitive for the low concentrations encountered in the lake but the 1987 measurements indicate that the concentrations in 1987 were about 17% higher than in 1973.

Iron concentrations were much higher after impoundment; 241% higher in 1986 and 293% higher in 1987 (Table 2). As already discussed, much or all of this increase may be attributable to the change in analytical methods.

Manganese concentrations were much lower in 1987, by at least 78%, than in 1973 (Table 2).

Transparency at the mainstem stations was lower in both 1986 (by about 23%) and 1987 (by about 33%) than in 1973 (Table 3) Suspended solids concentrations (NFR) have not increased markedly since impoundment but the detection limit employed in 1987 was too high to determine if a decrease has occurred (Table 3). Dissolved solids (TDS) concentrations were somewhat lower at the mainstem stations in 1986 than in 1973, particularly at station 1, but were about the same in 1987 as before impoundment. Specific conductance was slightly (about 10%) lower than prior to impoundment.

4.1.2 Threepoint Lake

4.1.2.1 Spatial and Annual Variation

There was notable spatial variation in a number of water quality parameters in Threepoint Lake. Turbidity was 5-13% higher at station 2 and 19-24% higher at station 3 than at station 1 in 1986-87 (Table 4). The suspended sediment concentration (NFR) at station 1 was 48% higher than at either of stations 2 or 3 in 1987. Dissolved solids concentrations (TDS) were about 15% higher at stations 2 and 3 than at station 1 in 1986 and were about 6% higher in 1987. Colour was particularly variable, both among the stations and between years, and was 25-30% lower at station 3 than at station 1 in 1986-87. The lowest colour was measured at station 2 in 1986 but was highest there in 1987. At stations 1 and 3, colour declined about 70% from 1986 to 1987 while colour at station 2 increased 236% during the same period.

Concentrations of most major ions, and particularly SO_4^{2+} and Na^+, were higher at stations 2 and 3 than at station 1 in 1986 (Table 5). Major ion levels were lower overall at the three stations in 1987. The decreases were

Table 4. Comparison of seasonal mean transparency, turbidity, dissolved and suspended solids concentrations, and colour in Threepoint Lake before and after Churchill River diversion.

Station	1972	1973a	1973	1974	1986 1	1986 2	1986 3	1987 1	1987 2	1987 3
Secchi (m)			0.5		0.64	0.65	0.5	0.6	0.59	0.59
Turbidity (NTU)	6.1	4.9		18	8.4	8.8	10.0	8.8	9.9	10.9
TR (mg L^{-1})								99.5	103.3	106.5
NFR	28		9					4.8	3.0	3.5
TDS			65		120.0	138.7	138.0	89.8	95.6	95.6
Conductivity (uS cm^{-1})										
Lab (Ward)	112	118		107	135	167	168	105	107	105
Field			142		108	106	107	114	115	112
Calculated								112	115	114
Lab (DFO)								102	106	103
Colour (true)	37	28		40	23.3	9.3	17.5	14.0	22.0	10.0

Data sources
1972 Morrelli (1974), July 12 to September 27
1973a Morrelli (1974), June 11 to September 21
1973 Cleugh (1974), July 18
1974 Morrelli (1974), July 23
1986 this study, June 9 to August 20
1987 this study, May 14 to August 31

Table 5. Comparison of seasonal mean pH and concentrations (mg L^{-1}) of anions, cations, and metals in Threepoint Lake before and after Churchill River diversion.

Station	1972	1973	1973a	1986 1	1986 2	1986 3	1987 1	1987 2	1987 3
Anions									
Cl^-	0.7	1.2	1.0	<2	<2	<2	1.1	1.0	1.1
SO_4^{2-}	2.2	4.2	3.4	3.3	11.8	10.1	2.4	2.4	2.3
Cations									
Ca^{2+}	16.2	17.0	18	18.1	19.0	19.2	12.3	13.0	12.5
Mg^{2+}		4.61		5.92	7.12	7.24	4.47	4.69	4.53
Na^+	1.8	2.23	2.2	3.70	6.64	6.58	2.95	2.89	2.91
K^+	0.7	0.92	0.9	<5	<5	<5	1.13	1.08	1.15
pH									
lab	7.9	8.03	7.7	7.90	8.02	7.95	7.85	7.76	7.78
field				7.4	7.4	7.4	7.4	7.4	7.4
Metals									
Fe	0.13	0.03	0.14	0.34	0.38	0.42	0.45	0.45	0.45
As							<0.001	<0.001	<0.001
Cd							<0.001	<0.001	<0.001
Cu	0.004		<0.002				<0.01	<0.01	<0.01
Zn	0.021		<0.002				<0.01	<0.01	<0.01
Pb	<0.006		<0.005				<0.005	<0.005	<0.005
Ni							<0.005	<0.005	<0.005
Mn	<0.007	<0.02	<0.012				<0.02	<0.02	<0.02

Data sources
1972 Morrelli (1974), July 23 to September 27
1973 Cleugh (1974), July 18
1973a Morrelli (1974), June 11 to September 21
1986 this study, June 9 to August 20
1987 this study, May 14 to August 31

greater at stations 2 and 3 than at station 1 with the result that levels were about the same at the three stations in 1987. Although this appears to be a reduction relative to 1986, the change is more likely the product of an increase of major ion concentrations in 1986 compared with other years. Diversion flows through the Notigi control structure were reduced about 30% in 1986 (G. McCullough, pers. comm.). When the flows were restored in 1987, major ion concentrations decreased to levels that were comparable to concentrations measured upstream in Rat Lake (Tables 2 and 5). With the lower diversion flows in 1986, major ion concentrations at stations 2 and 3 in particular may have been more affected by the Burntwood River than would commonly occur in the period since diversion. Local influences such as shoreline erosion and sediment resuspension also might be expected to have a greater effect on water quality when diversion flows are reduced.

None of this spatial or year-to-year variation was evident in the nutrient parameters (Table 6). Concentrations were about the same at the three stations in each year and varied little from 1986 to 1987. The only exception is silica, which was 30% higher at station 2 than at either station 1 or 3 in 1987. No silica measurements were made in 1986.

4.1.2.2 Comparison with 1972-73

Because of the flow variation in Threepoint Lake from 1986 to 1987 and its apparent effect on major ion concentrations in the lake, no clear picture of the changes in major ion concentrations in the lake since diversion can be described. Any changes or trends may become more clear when the 1988 data can be included in the analysis.

Magnesium levels in 1986 were generally higher than in 1973 by about 28% at station 1 but by about 55% at stations 2 and 3 (Table 5). In 1987,

Table 6. Comparison of seasonal mean nutrient concentrations in Threepoint Lake before and after Churchill River diversion.

Station		1973	1986 1	1986 2	1986 3	1987 1	1987 2	1987 3
NO_3-N	(ug L^{-1})	4	<1	3	<1	4	6	2
NO_2-N			1	1	2	<1	<1	<1
NH_3-N			27	27	40	24	22	30
TDN		814	327	343	363	288	364	308
Susp N		172	61	68	76	62	79	70
TDP	(ug L^{-1})	20	18	18	20	13	16	13
Susp P		15	12	13	15	14	15	15
DIC	(umole L^{-1})	1110	937	897	883	942	946	950
DOC	(umole L^{-1})	1055	623	703	800	614	794	606
Susp C	(ug L^{-1})	1140	467	520	537	508	584	562
SrSi	(mg L^{-1})	1.31				0.80	1.07	0.83

Data sources
1973 Cleugh (1974), July 18
1986 this study, June 9 to August 20
1987 this study, May 14 to August 31

concentrations at all stations were comparable to 1973. Similarly, Na^+ levels were 78% higher than before development at station 1 in 1986 but were over 3 times higher at stations 2 and 3. In 1987, concentrations were the same at the three stations and averaged 40% higher than in 1972-74. Following this trend, Ca^{2+} levels in 1986 were near the high end of the pre-development range and were near the low end of that range in 1987. Again, the limit of detection for potassium analyses used in 1986 was not sufficiently sensitive for the low concentrations encountered in the lake but the 1987 measurements indicate that levels are about 30% higher than in 1972-74. Iron concentrations were over 3 times higher in 1986 and over 4 times higher in 1987 than in 1972-74. Again, this increase since impoundment has been attributed to the change in analytical methods.

Decreases in the concentrations of major nutrients similar in magnitude to those noted for Rat Lake also appear to have occurred in Threepoint Lake since diversion (Table 6). These changes can be stated with considerably less confidence than for Rat Lake, however, because the entire pre-development nutrient data base consists of a single sampling date in July 1973. Concentrations of TDN were about 60% lower in 1986-87 and suspended N was 60-70% lower. TDP was at pre-development levels in 1986 but was about 30% lower in 1987. Suspended P concentrations were the same as before development. DIC was 15-18% lower in 1986-87, DOC was 33-36% lower, and suspended C was about 50% lower. Silica was 30% lower in 1987 than in 1973.

There have not been marked changes in either water transparency or turbidity with development (Table 4). Suspended sediment concentrations (NFR) were lower in 1987, by a factor of 2-3, than in 1972-73. Dissolved solids concentrations were a factor of 2 higher in 1986 and about 40% higher in 1987 than in 1973. Colour was lower in 1986 and 1987 than in any pre-development

year and this reduction is greater than that which might be attributable to the change in analytical procedure.

4.2 Phytoplankton Composition Biomass and Periodicity

4.2.1 Spatial and Annual Variation

The lakes sampled in the Rat-Burntwood river system support distinctive phytoplankton communities. In general algal biomass was highest in spring, immediately following ice-out, in both Rat and Threepoint lakes (Figures 8,9,10, and 11). This trend was less evident in Rat lake in 1988 primarily because of the later start of sampling; early June in 1988 compared with mid-May in 1987. The spring pulse was the product of Melosira sp. (diatom) blooms in both lakes; diatoms accounted for 82-95% of total biomass during the spring biomass peak in 1987 and for 72-88% of total biomass in 1988. Peak biomass in Rat and Threepoint lakes was similar in 1987, ranging from 3 000-6 000 mg m^{-3}, depending on station location. Comparisons of the size of the spring blooms in 1988, either between the lakes or with the previous year, are not particularly meaningful due to the much later initiation of sampling in 1988 with the likelihood that at least some of the bloom was missed.

Phytoplankton biomass in both lakes was uniformly low in both lakes after the spring bloom (Figures 8,9,10, and 11). Mean summer (June -September) biomass (all stations) in Threepoint Lake was higher than in Rat Lake in both years (by 56% in 1987 and by 44% in 1988) largely due to the persistence of diatom dominance into July. No group consistently dominated the summer phytoplankton community in Rat Lake. Mean summer biomass was higher in 1988 than in 1987 in both Rat Lake, by 36%, and Threepoint Lake (by 25%).

Peak biomass in Rat lake was lower at station 1, the inflow station, than at the stations farther down the lake in 1987 (Figure 8). Mean summer biomass

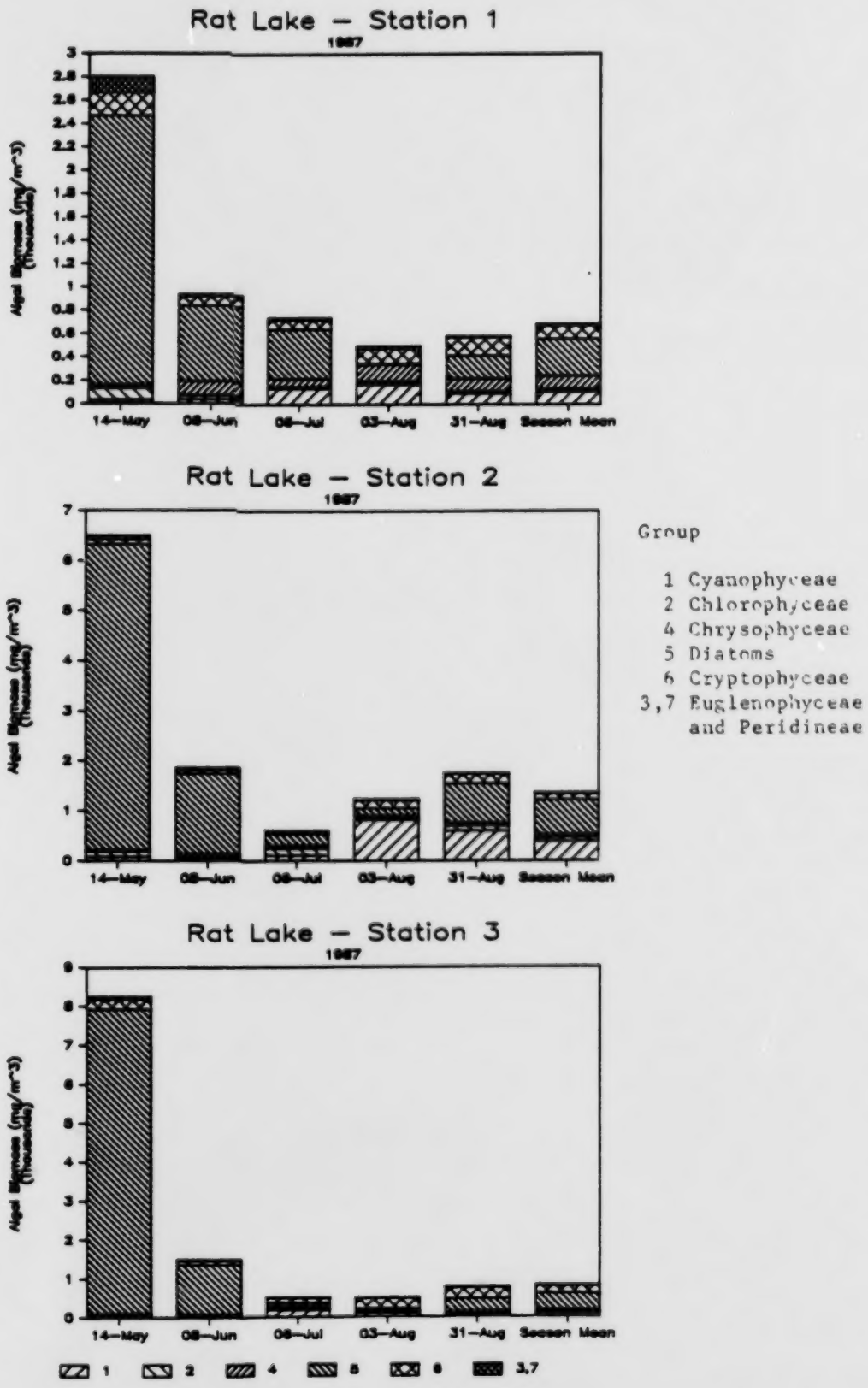

Figure 8. Algal biomass and taxonomic composition in Rat Lake during the summer of 1987. Season mean excludes the May sample.

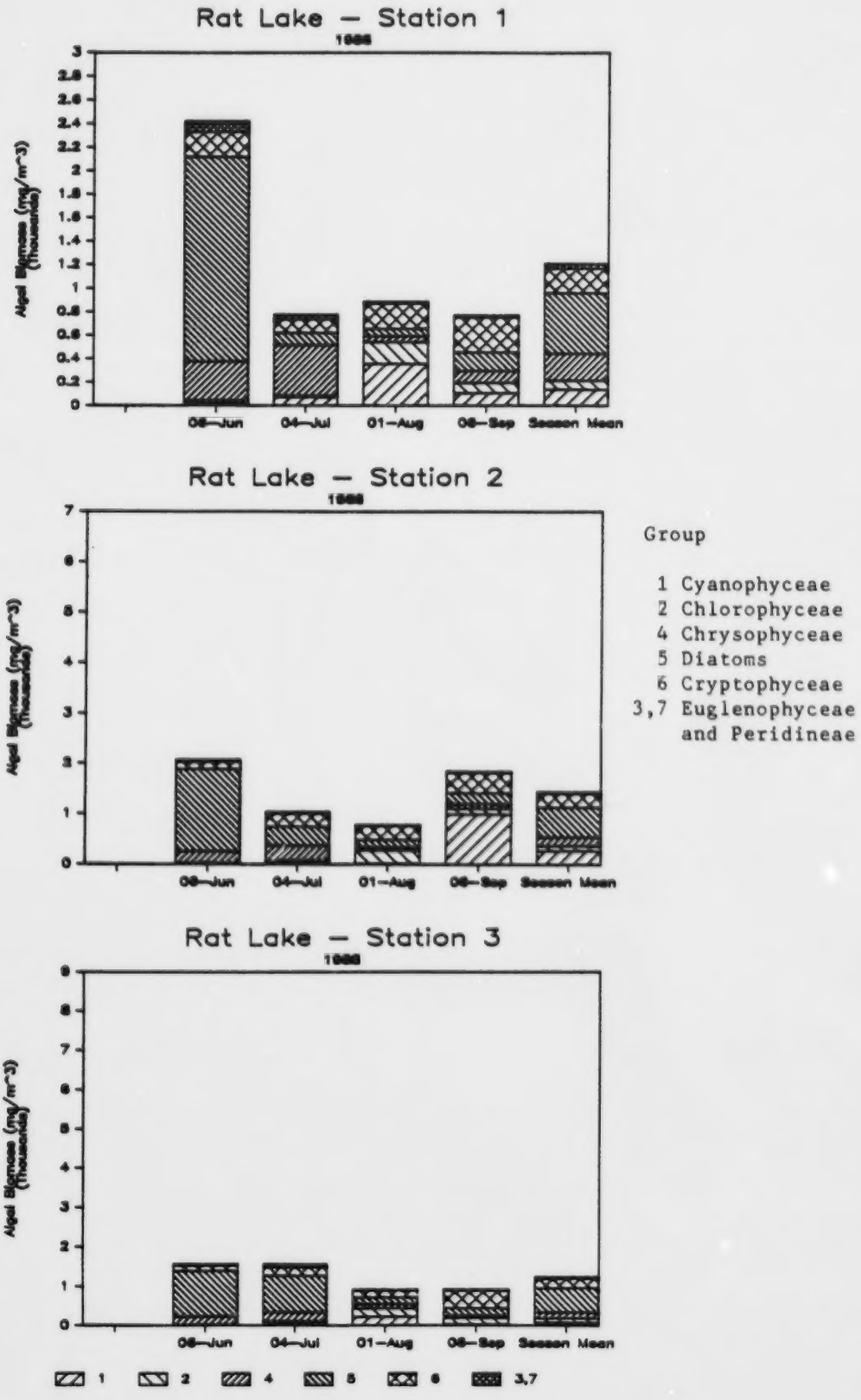

Figure 9. Algal biomass and taxonomic composition in Rat Lake during the summer of 1988.

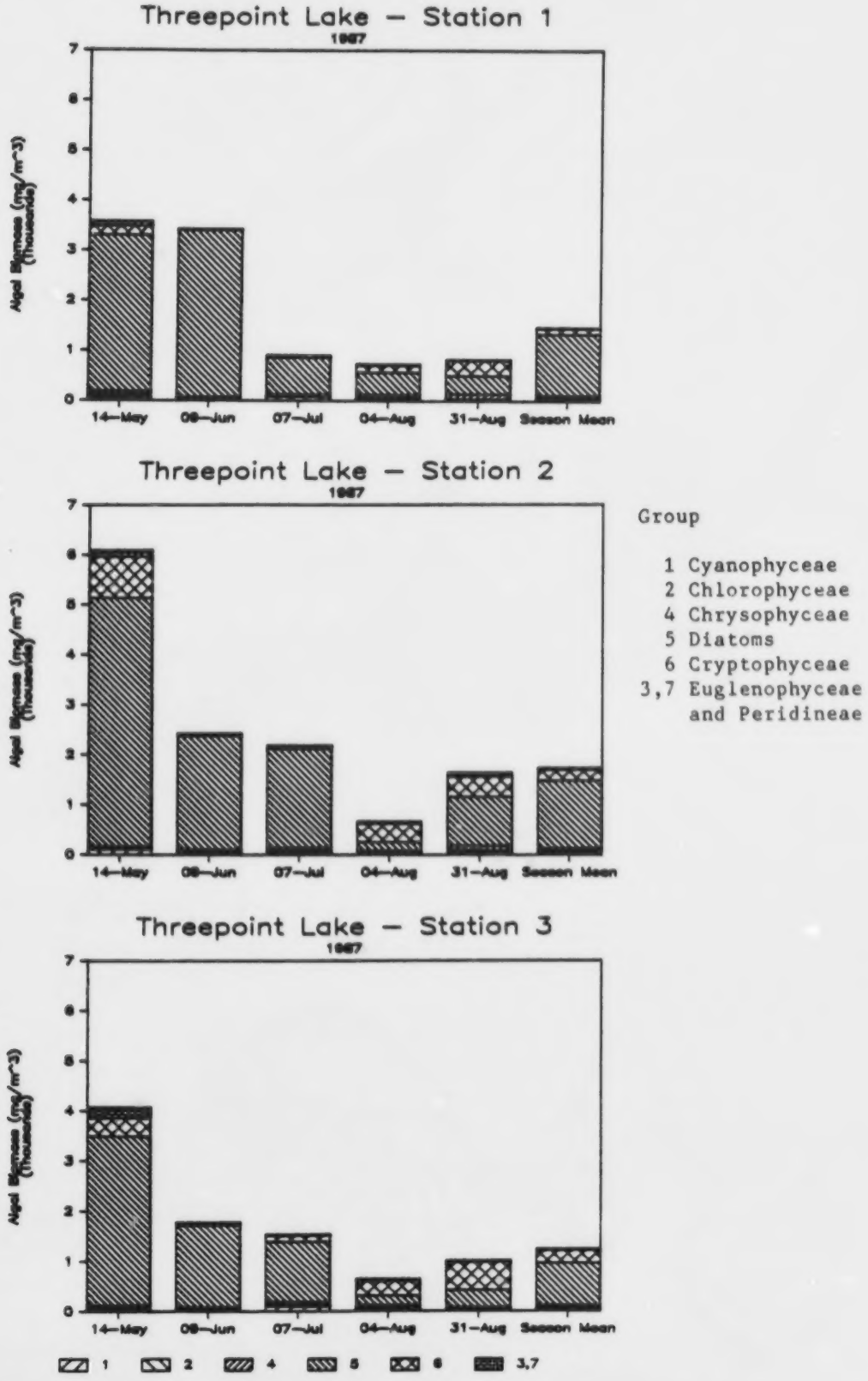

Figure 10. Algal biomass and taxonomic composition in Threepoint Lake during the summer of 1987. Season mean excludes the May sample.

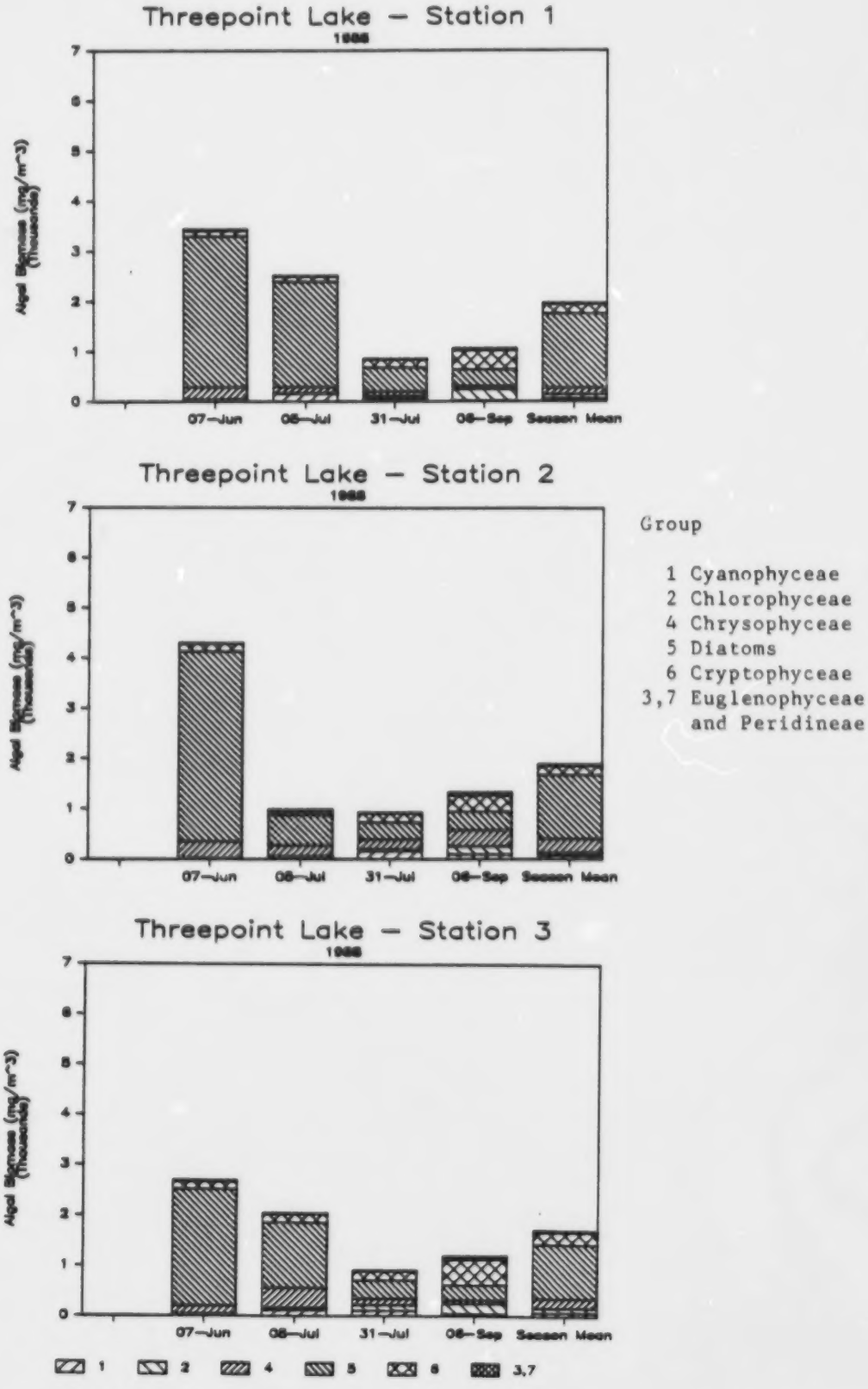

Figure 11. Algal biomass and taxonomic composition in Threepoint Lake during the summer of 1988.

was higher at the backwater station (station 2) than at either main-stem station in both years although the difference was smaller in 1988 (Figures 8 and 9). The increase in lake mean summer biomass in 1988 was largely the result of higher standing crops at stations 1 and 3.

Peak biomass in Threepoint Lake was highest at station 2, the major inflow station at the confluence of the Rat and Burntwood Rivers, than at either stations 1 or 3 in 1987 (Figure 10). This may indicate that the higher biomass at station 2 was the product of drift from lakes upstream. Mean summer biomass also was higher at station 2 in 1987 but there was no clear difference in summer biomass among the stations in 1988 (Figures 10 and 11). The increase in lake mean biomass in 1988 was largely due to higher standing crops at stations 1 and 3.

4.2.2 Rat Lake - Comparison with 1973

The composition and periodicity of the phytoplankton community in Rat Lake appear to have changed considerably from that prior to impoundment. In 1973, the only year prior to impoundment for which data are available, phytoplankton biomass peaked in late August and this peak was the product of a blue-green (cyanophyte) bloom (Hecky and Harper 1974; Figure 12). Mean summer (June-September) biomass was much higher in 1973, averaging about 2800 mg m^{-3} (Figure 12), than in either 1987 (1000 mg m^{-3}; Figure 8) or 1988 (1300 mg m^{-3}; Figure 9). These reduced phytoplankton standing crops in Rat Lake are probably the combined result of increased turbidity (Table 3) and flushing rate as well as decreased nutrient availability (Table 1).

The phytoplankton community of Threepoint Lake was not sampled for the LWCNR study.

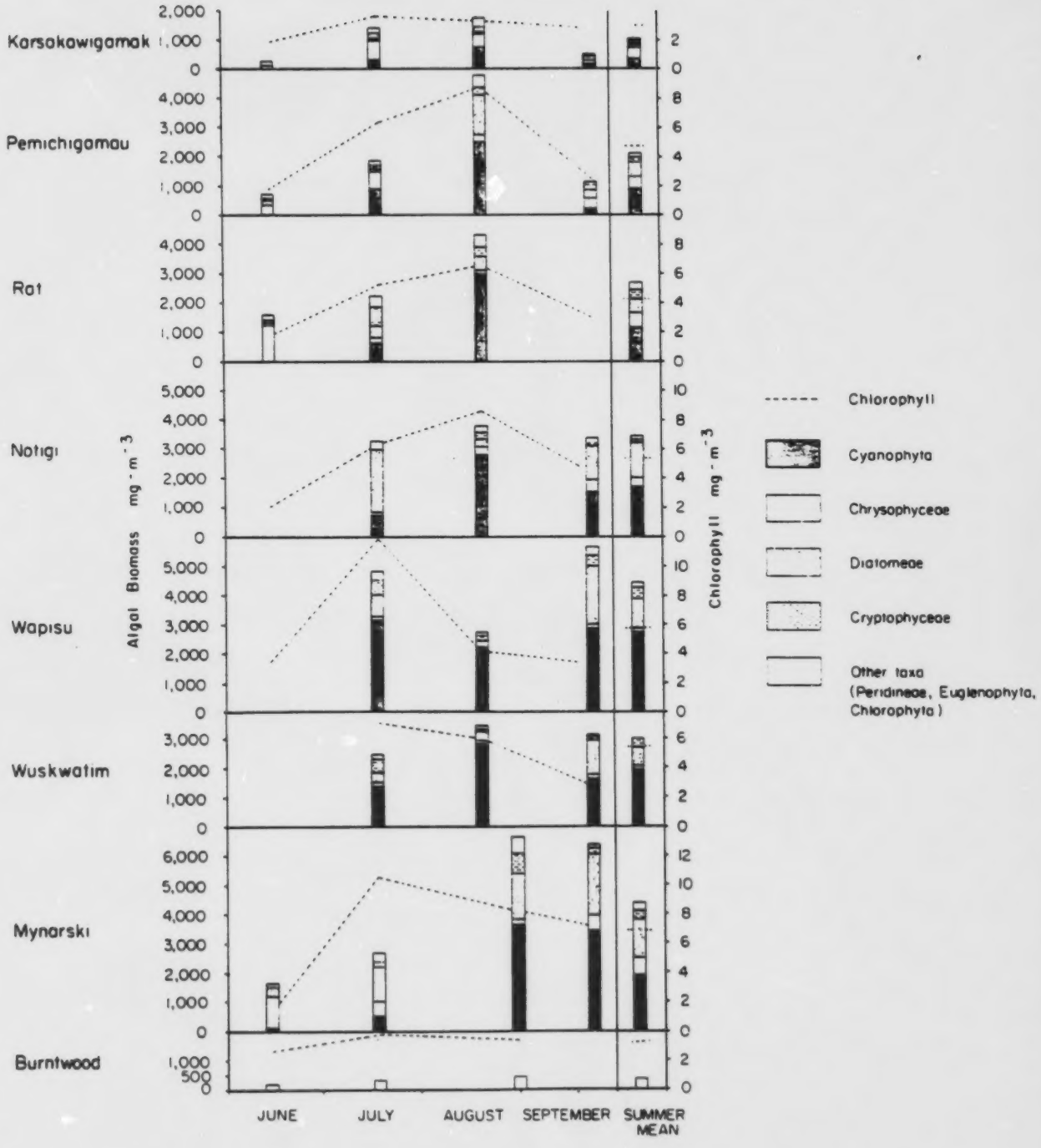

Figure 12. Algal biomass, taxonomic composition, and chlorophyll for some Rat-Burntwood lakes during the summer of 1973. **From: Hecky and Harper (1974)**

4.3 Zooplankton Composition Biomass and Periodicity

4.3.1 Rat Lake

Seasonal mean zooplankton standing stocks in Rat Lake in 1987 and 1988 ranged from 297 to 530 ug L^{-1} (Figures 13 and 14), which is about in the middle of the range measured at the mainstem stations in Cross and Sipiwesk lakes (Section 5, Figures 20,21, 25, and 26). There was little difference in seasonal mean zooplankton biomass among the three stations in Rat Lake in 1987; the range was only 5% the mean (Figure 13). There was somewhat more variation among the stations in 1988, the range was about 25% of the mean (Figure 14). The highest mean biomass in 1988 was at station 3, near the outlet of the lake, with the lowest biomass in the backwater at station 2. Lake-mean biomass was 25% higher in 1988 than in 1987. Copepods dominated at all stations, accounting for 50-65% of the total, followed by cladocerans, which represented 25-36% of mean total biomass.

4.3.2 Threepoint Lake

Zooplankton biomass in Threepoint Lake averaged about half that in Rat Lake in both 1987 and 1988 which, at 168-225 ug L^{-1} (Figures 15 and 16), was at the low end of the range measured at the mainstem stations in Cross and Sipiwesk lakes (Section 5, Figures 20,21,25, and 26). As in Rat Lake, lake-mean biomass was higher in 1988, by 34%, than in 1987. The highest biomass occurred at station 2, near the confluence of the Rat and Burntwood rivers, and the lowest biomass at station 3, near the lake outflow, in both years. Copepods were the community dominants, accounting for 59-61% of mean biomass, as found in Rat Lake and at most of the mainstem stations on the Nelson River. The balance of community biomass was about equally split between rotifers and cladocerans.

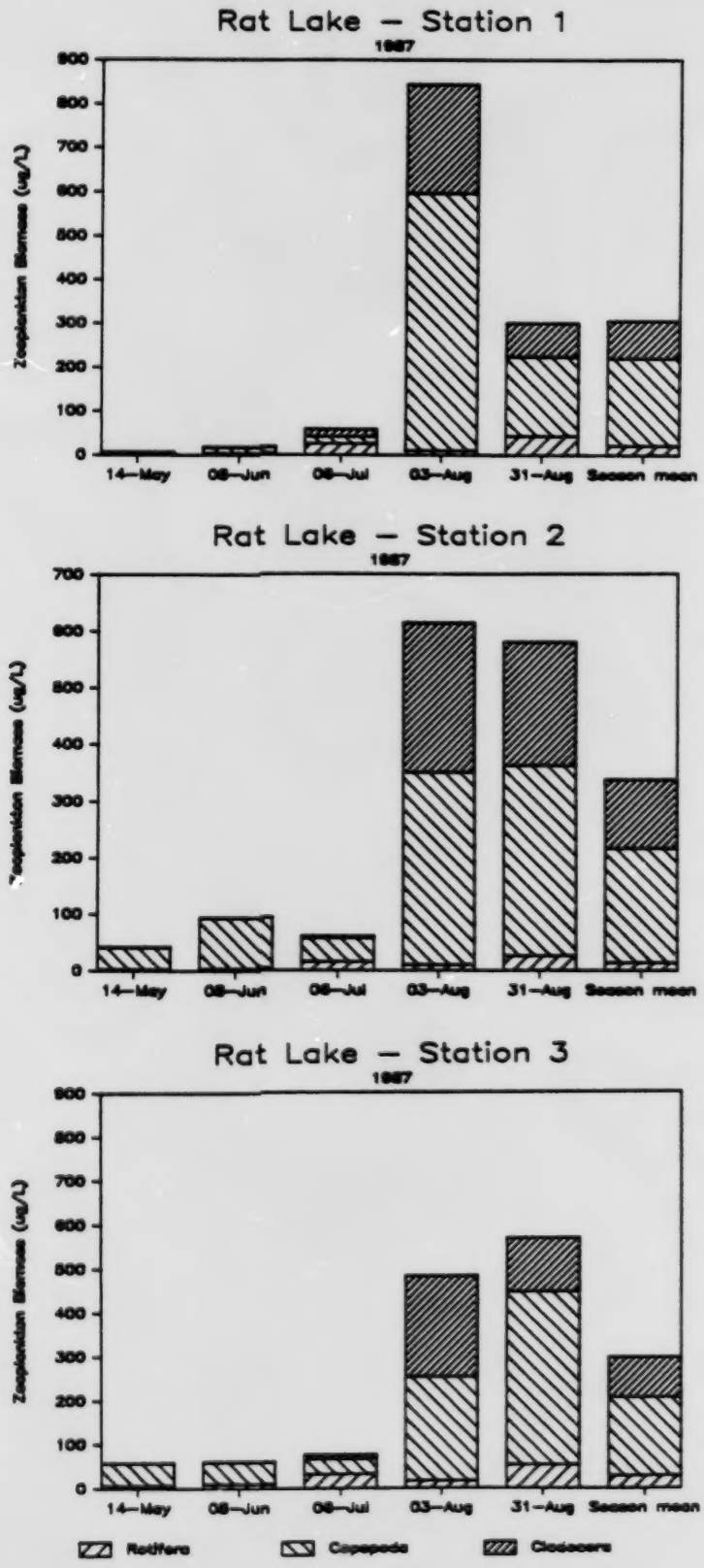

Figure 13. Distribution of zooplankton biomass among the major taxonomic groups in Rat Lake during the summer of 1987. Season Mean excludes the May sample.

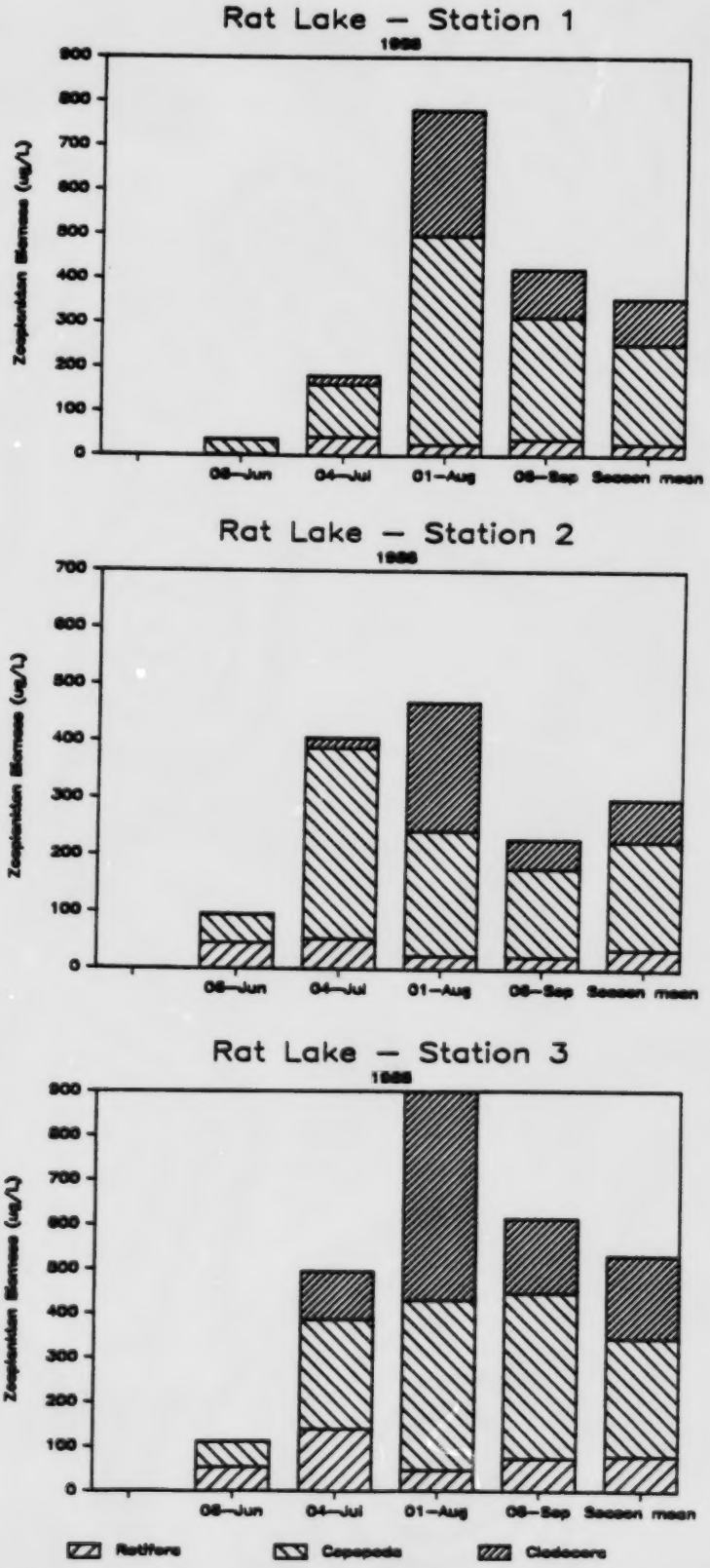

Figure 14. Distribution of zooplankton biomass among the major taxonomic groups in Rat Lake in the summer of 1988.

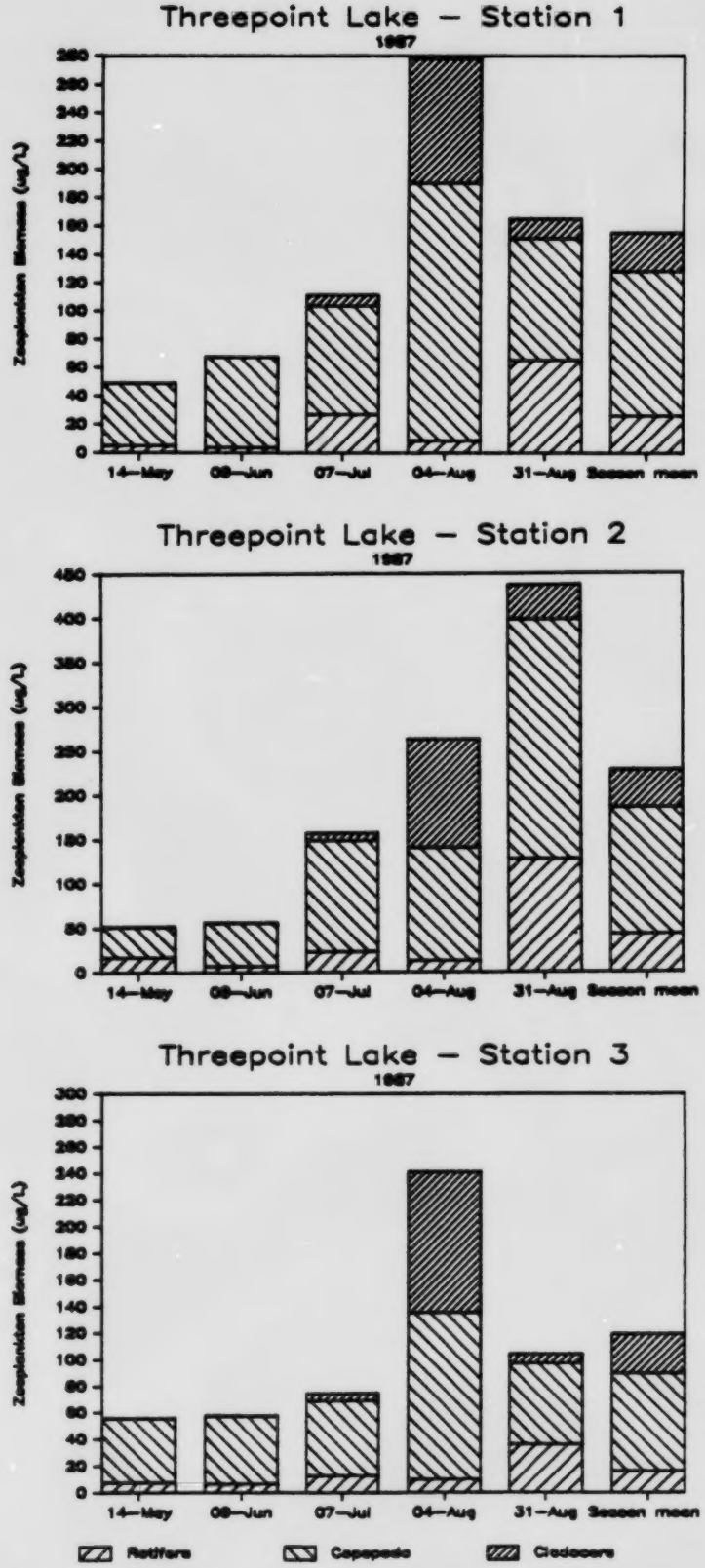

Figure 15. Distribution of zooplankton biomass among the major taxonomic groups in Threepoint Lake in the summer of 1987. Season mean excludes the May sample.

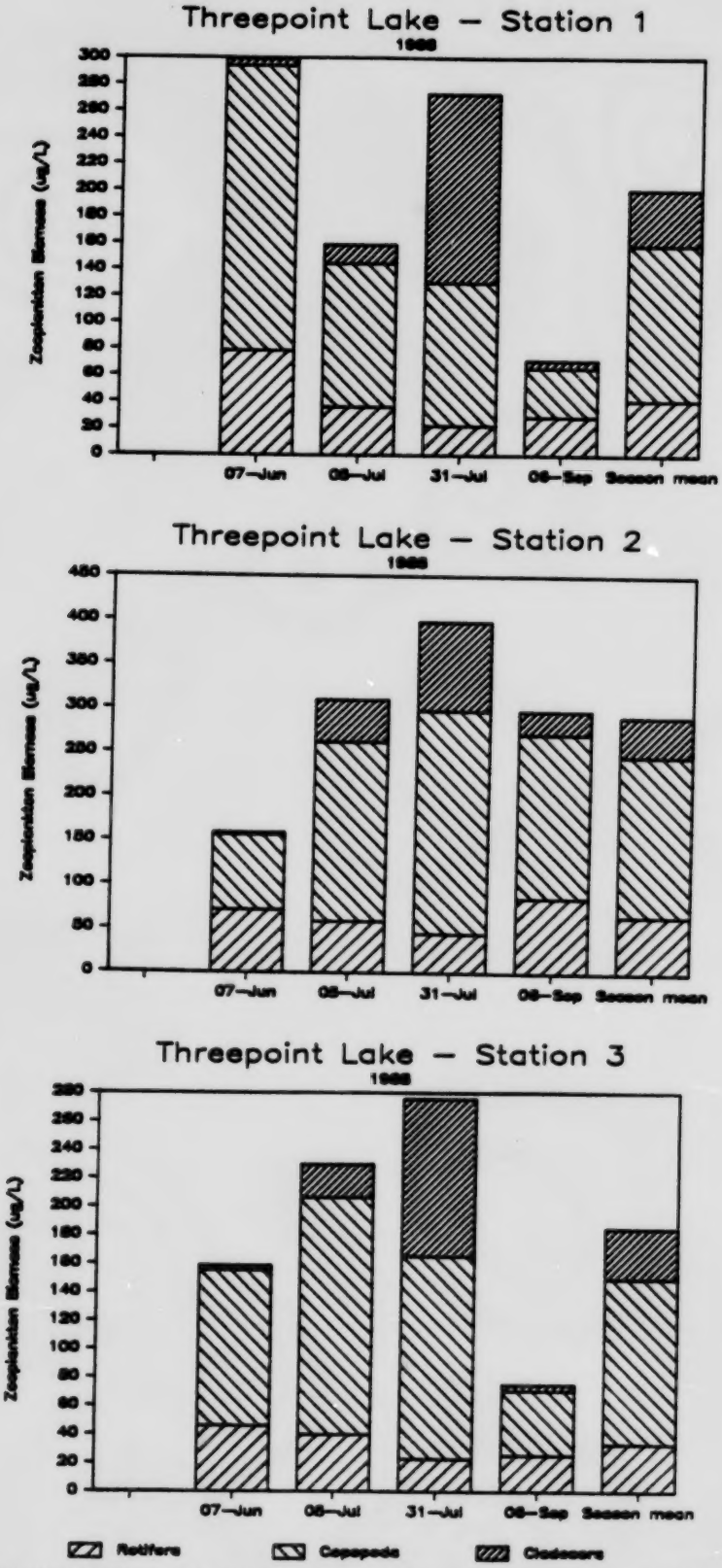

Figure 16. Distribution of zooplankton biomass among the major taxonomic groups in Threepoint Lake in the summer on 1988.

5.0 Limnological Changes in the Upper Nelson Lakes

5.1 Cross Lake

5.1.1 Water Quality

5.1.1.1 Spatial and Annual Variation

As found in other lakes on the Nelson River (Sections 5.2.1, 6.1.1, 6.2.1), the backwater stations (2 and 3) supported higher concentrations of several, but not all, major nutrients and lower cation and anion concentrations than the mainstem station (1). Nitrate-nitrogen levels were considerably (50-85%) lower at the backwater stations in both 1986 and 1987 (Table 7). However, there was no clear difference in NH_3-N levels between the backwaters and the mainstem and TDN concentrations were 25% higher in the backwater in 1986 and 53% higher in 1987. Suspended N and C concentrations were 25-200% higher in the backwaters in 1986 and were over 4 times higher than on the mainstem in 1987. There was no difference in TDP concentrations among the stations in either 1986 or 1987. Suspended P concentrations also were similar at the three stations in 1986 but were 75% higher at the backwater stations in 1987. DIC levels were about 40% lower at the backwater stations in both 1986 and 1987 but DOC was 17% higher at stations 2 and 3 in 1986 and was 33% higher in 1987.

Concentrations of all anions and cations were lower at the backwater stations than at the mainstem station in each of 1985, 1986 and 1987 (Table 8). The largest differences in anion concentrations were observed in 1985 (85% lower) with this differential decreasing in each of the next two years (60-65% lower in 1986 and 55-60% lower in 1987). The greatest difference in cation concentrations (52-85% lower) also was observed in 1985, but the smallest difference (14-36% lower) was in 1986, while concentrations were 23-50% lower in 1987.

Table 7. Comparison of seasonal mean nutrient concentrations in Cross Lake before and after Lake Winnipeg regulation.

Station		1972	1973	1986			1987		
			240	1	2	3	1	2	3
NO_3-N	(ug L^{-1})		3	6	3	3	11	1	2
NO_2-N				1	<1	<1	<1	<1	<1
NH_3-N				17	17	20	24	30	24
TDN			382	360	427	470	392	636	562
Susp N			95	66	83	135	151	643	677
TDP	(ug L^{-1})		16	21	17	17	15	15	14
Susp P			18	10	9	14	28	53	45
DIC	(umole L^{-1})		1741	1917	1163	1123	1699	1042	1132
DOC	(umole L^{-1})		643	673	763	817	658	922	834
Susp C	(ug L^{-1})		856	503	627	1117	1294	4858	5788
SrSi	(mg L^{-1})	1.3	0.66				0.49	0.34	0.30

Data sources
1972 Koshinsky (1974), July 26 to December 11
1973 Cleugh (1974) June 13 to September 26
1986 this study, June 9 to August 17
1987 this study, May 13 to September 1

Table 8. Comparison of seasonal mean pH and concentrations (mg L^{-1}) of anions, cations, and metals in Cross Lake before and after Lake Winnipeg regulation.

Station	1965 West	1965 East	1972	1973 240	1985 1	1985 2	1985 3	1986 1	1986 2	1986 3	1987 1	1987 2	1987 3
Anions													
Cl^-		2.0	17.0	18.2	13.5	2.5	<2.0	10	6	3	8.9	1.6	5.6
SO_4^{2-}		5.8	27.9	24.7	23.5	4.7	2.1	20	9	8	16.2	3.5	10.9
Cations													
Ca^{2+}		13.6	32.2	28.8	29.5	14.8	13.2	23.5	17.1	16.7	21.9	14.9	18.7
Mg^{2+}		4.4		10.7	12.1	5.1	3.9	9.3	6.2	5.6	8.4	4.8	6.8
Na^+		19.0	16.1	11.5	14.8	3.3	1.1	5.6	5.4	4.2	8.6	2.5	6.0
K^+		1.2	2.3	2.4	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	1.8	1.0	1.0
pH													
lab	7.8	7.8	8.1	8.22	8.3	7.8	7.8	8.08	7.98	7.98	7.87	7.96	7.96
field								7.6	7.5	7.5	7.7	7.8	7.8
Metals													
Fe		0.34	0.11	0.13	0.37	0.63	0.69	0.30	0.19	0.27	0.40	0.51	0.40
As											<0.001	<0.001	<0.001
Cd											<0.001	<0.001	<0.001
Cu			0.002								<0.01	<0.01	<0.01
Zn			0.006								<0.01	<0.01	<0.01
Pb			0.007								<0.005	<0.005	<0.005
Ni											<0.005	<0.005	<0.005
Mn			<0.005	<0.01							<0.03	<0.04	<0.03

1965 Driver and Doan (1972)
1972 Koshinsky (1974), July 26 to December 11
1973 Cleugh (1974) June 13 to September 26
1985 this study, July 10 and August 27
1986 this study, June 9 to August 17
1987 this study, May 13 to September 1

Total iron concentrations at the backwater stations always differed from levels at the mainstem station but were not consistently higher or lower (Table 8). Concentrations were 78% higher in 1985, were 24% lower in 1986, and were 14% higher in 1987. This broad variation was primarily due to fluctuations in iron concentrations at the backwater stations.

Water transparency and turbidity also were consistently different at the backwater stations than on the mainstem but, again, the direction of this difference varied from year to year. Secchi visibility was 22-44% lower at the backwaters in 1985, 2.2-2.8 times higher in 1986, but was only about 10% higher in 1987 (Table 9). Similarly, turbidity was 2.5 times higher at the backwaters in 1985, 33% lower in 1986, and 16% lower in 1987. Suspended sediment concentrations were much higher at the backwater stations, by a factor of 1.6-4.8 in 1985 and by a factor of 3 in 1987. Dissolved solids concentrations were consistently lower at the backwater stations but the magnitude of this difference decreased, from 66% lower in 1985 to 33% in 1986 to 23% in 1987. The same pattern of variation was evident in specific conductance. Colour was consistently higher at the backwater stations, but the differential from the mainstem decreased from a factor of 2 in 1985 to 1.3 in 1987.

5.1.1.2 Mainstem Station - Comparison with 1972-73

Concentrations of nutrients in the dissolved fraction generally were the same or higher in 1986-87 than in 1965-74. Nitrate-nitrogen concentrations were 2-3.5 times higher, TDP was 30% higher in 1986 but about the same as before development in 1987 (Table 7). TDN, DIC, and DOC were unchanged. Concentrations of C, N, and P in the particulate fraction were 30-50% lower than the pre-development values in 1986 but were 50-60% higher than the baseline values in 1987. The mean silica concentration was 26% lower in 1987

Table 9. Comparison of seasonal mean transparency, turbidity, dissolved and suspended solids concentrations, and colour in Cross Lake before and after Lake Winnipeg regulation.

Station	1965 West	1965 East	1972	1973 240	1985 1	1985 2	1985 3	1986 1	1986 2	1986 3	1987 1	1987 2	1987 3
Secchi (m)	1.5	1.5-2.5		0.5	0.95	0.75	0.53	0.65	1.82	1.4	0.45	0.52	0.48
Turbidity (NTU)					5.3	11.3	15.3	8.7	5.0	6.7	17.4	15.1	14.1
TR (mg L^{-1})				185.0	66.0	98.0					195.0	140.0	143.5
NFR			8.6	14.8	7.0	11.0	33.5				8.8	28.8	23.8
TDS	143	95-96		186	175.0	55.0	63.5	155.0	110.0	98.0	164.4	110.0	129.4
Conductivity (uS cm^{-1})													
Lab (Ward)			308		296	127	96	226	129	136	203	118	167
Field				277	252	115	84	297	179	153	214	117	135
Calculated											271	129	147
Lab (DFO)											235	115	134
Colour (true)			22		5.0	10.0	10.0	10.0	16.7	15.0	10.0	14.0	12.5

1965 Driver and Doan (1972)
1972 Koshinsky (1974), July 26 to December 11
1973 Cleugh (1974) June 13 to September 26
1985 this study, July 10 and August 27
1986 this study, June 9 to August 17
1987 this study, May 13 to September 1

than in 1973.

Anion concentrations were lower in all of 1985, 1986, and 1987 with the magnitude of the pre/post difference increasing in each year. Chloride was 23% lower in 1985, 43% lower in 1986, and 49% lower in 1987 (Table 8). Sulfate ranged from 10% lower in 1985 to 38% lower in 1987. Cation concentrations were the same (Ca^{2+} and Na^{+}) or higher (Mg^{+}) than before development in 1985 but were 13-59% lower in 1986 and 21-37% lower in 1987.

Water transparency declined by about 50% between 1985 and 1987, but this range of measurements was within or near the pre-development range (Table 9). Suspended sediment concentrations in 1985 and 1987 were at the low end of the range measured in 1972-73. Dissolved solids concentrations were within the pre-development range. Field measurements of specific conductance in 1985 and 1986 were about the same as in 1973, but conductivity was about 25% lower in 1987. Colour was 50-75% lower in 1985-87 than in 1972.

Although few measurements were made in the backwater areas before development, those data which are available indicate that water quality was generally similar to that at present (Tables 7,8, and 9).

5.1.2 Phytoplankton Composition Biomass and Periodicity

5.1.2.1 Spatial and Annual Variation

Phytoplankton biomass at the mainstem station in Cross lake was dominated by a spring pulse in 1987 (Figure 17). Diatoms and chlorophytes jointly contributed over 80% of the biomass during this spring peak. The bloom disappeared by early June and biomass fluctuated about the 1000 mg m^{-3} level through to the beginning of September. Sampling started later in 1988 (June 7 compared with May 13 in 1987) and no spring pulse was evident at this time (Figure 18). As in 1987, biomass fluctuated about the 1000 mg m^{-3} level over

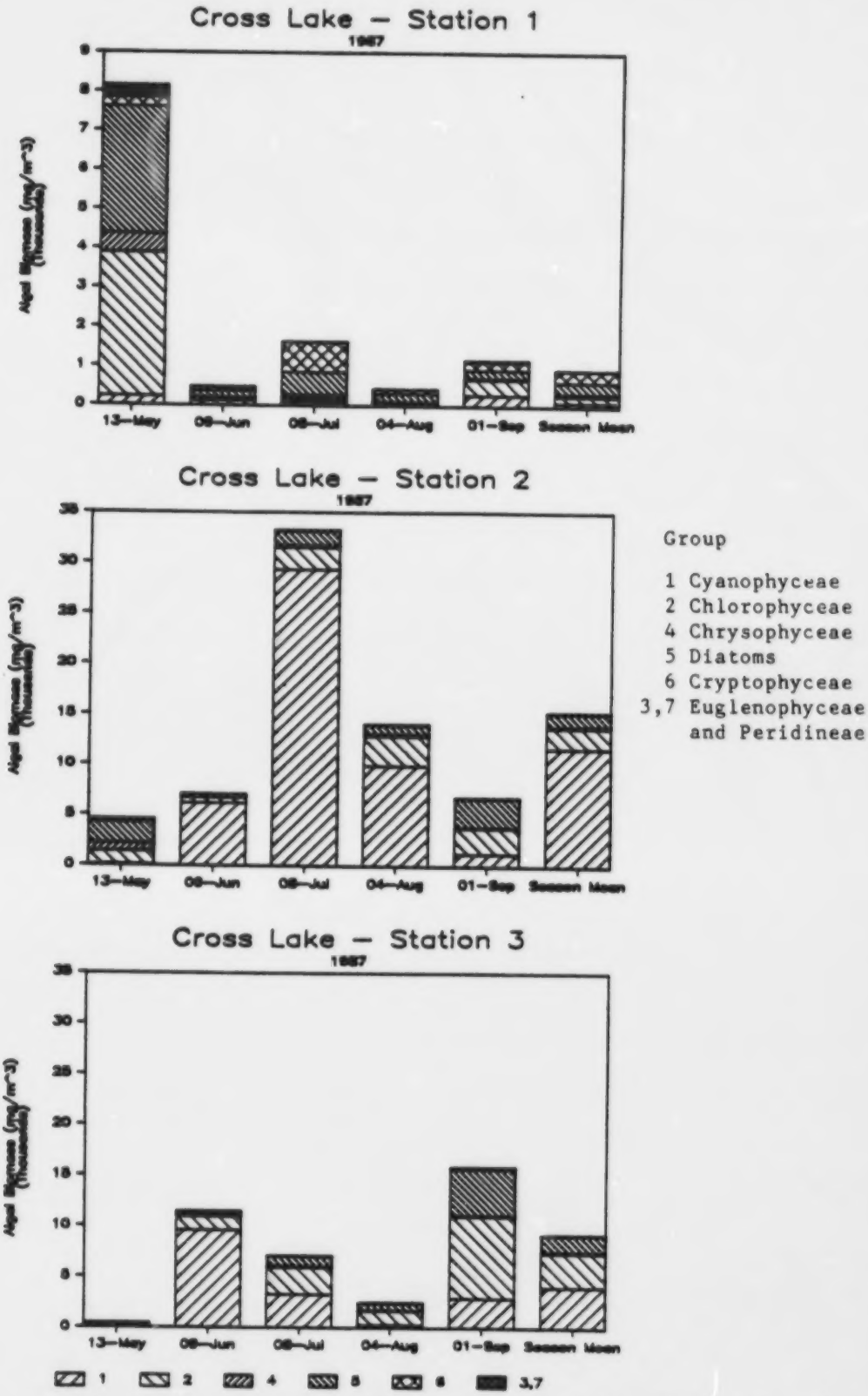

Figure 17. Algal biomass and taxonomic composition in Cross Lake during the summer of 1987. Season mean excludes the May sample.

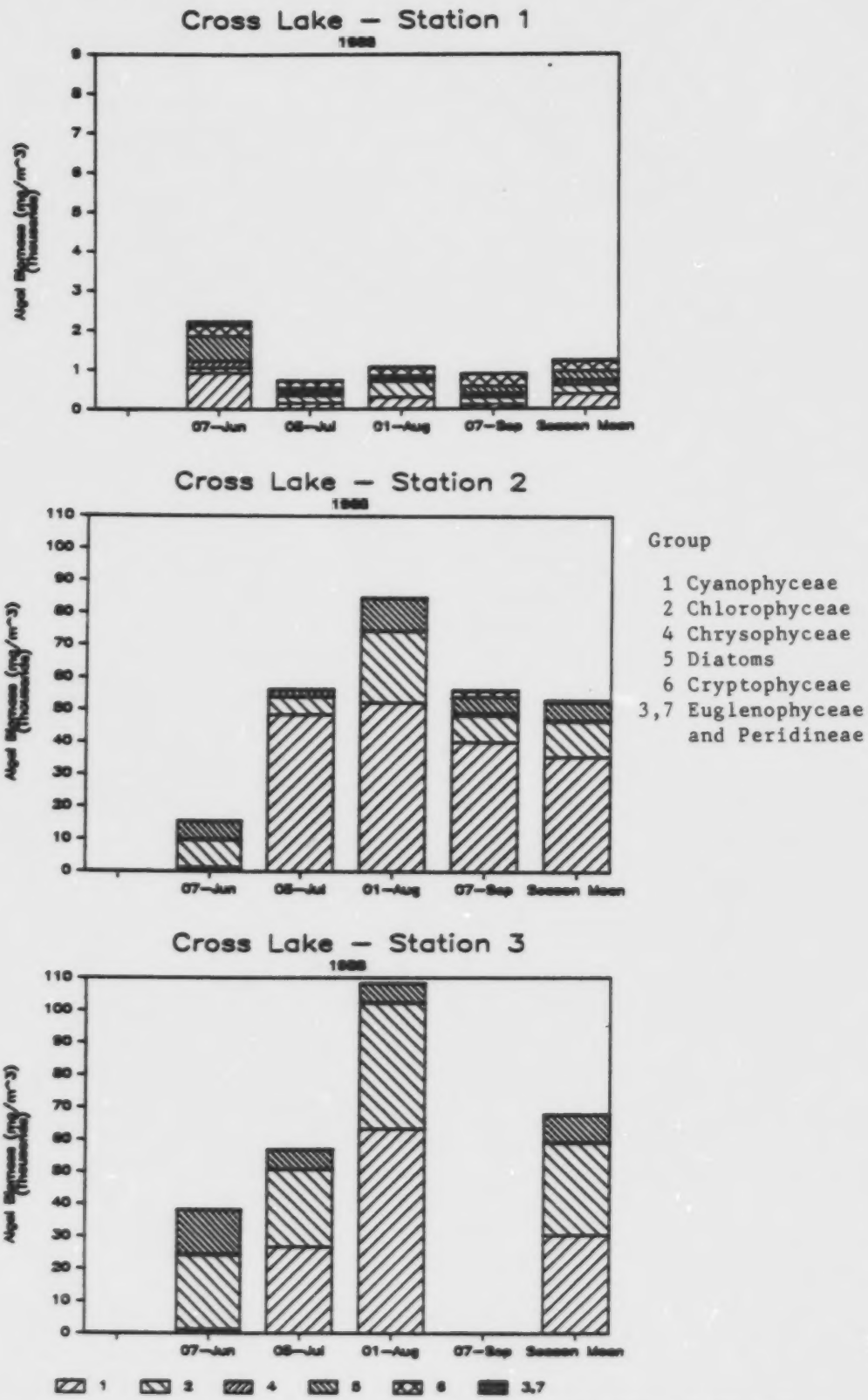

Figure 18. Algal biomass and taxonomic composition in Cross Lake during the summer of 1988.

the summer of 1988 with no single algal group dominating the community. Mean phytoplankton biomass in 1988 was about 30% higher than in 1987.

The backwater stations supported much higher phytoplankton biomass than the mainstem station in both years of study; by factors of 10-15 in 1987 and 50-65 in 1988 (Figures 17 and 18). Cyanophytes, chlorophytes, and diatoms were the only important taxa at either station 2 or 3 with the first and second groups most important overall. Cyanophytes, predominated at station 2 in both years while this group was co-dominant with chlorophytes at station 3. Biomass was highest in mid to late summer at both stations. Cyanophytes dominated the summer maximum at station 2 while cyanophytes and chlorophytes jointly contributed to the maximum at station 3.

The high phytoplankton standing crops in the backwater developed in the absence of markedly higher dissolved nutrient concentrations or transparency. Nutrient loading could possibly be higher in the backwater but this has yet to be quantified. A major difference between the backwater and the mainstem is probably flushing rate and this could explain the accumulation of phytoplankton biomass in the backwater.

5.1.2.2 Mainstem Station - Comparison with 1973

Standing crops at the mainstem station in 1987-88 were, on average, about a factor of three higher than in 1973 (Figures 17,18, and 19). Then as now, no single algal group dominated the community and there was no definable pattern of biomass fluctuation in the June through August period. No pre-development data were collected in the backwater areas.

The higher phytoplankton biomass at the mainstem station in the current study compared to 1973 occurred in the absence of higher dissolved nutrient concentrations or higher transparency. It seems unlikely the nutrient loading

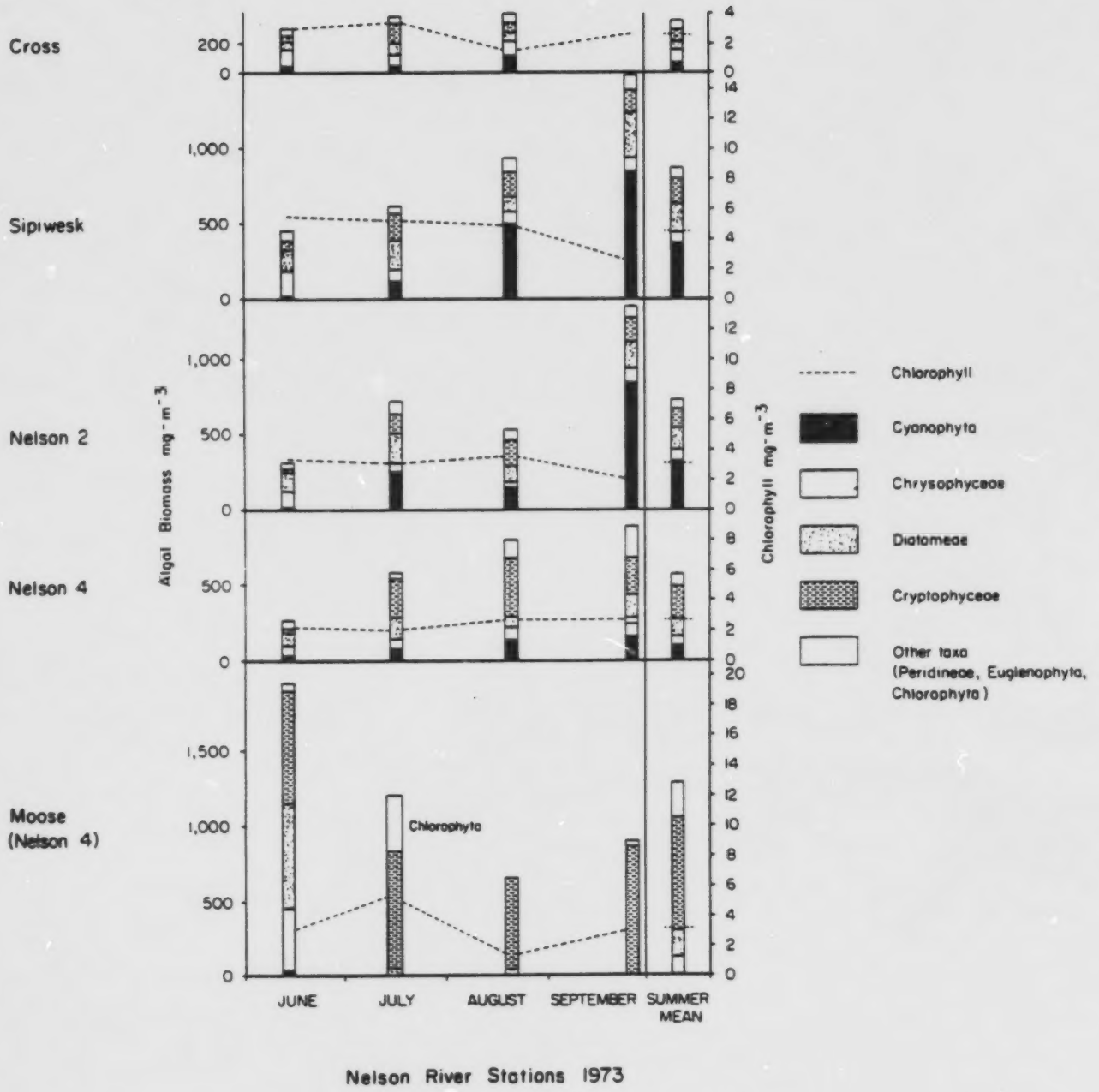

Figure 19. Algal biomass, taxonomic composition and chlorophyll for Nelson River stations during the summer of 1973. From: Hecky and Harper (1974).

in the mainstem has been elevated as result of flow regulation at Jenpeg but flow regulation itself may be responsible, allowing the phytoplankton to accumulate rather than being washed downstream. Other explanations include the possibility of more efficient collection and/or enumeration procedures in the present study or the location of sampling stations at different locations in the present study compared with the pre-development studies. The validity of all these explanations should be evaluated.

5.1.3 Zooplankton Composition Biomass and Periodicity

Zooplankton biomass was consistently higher at the backwater stations than at station 1 on the Nelson River mainstem. On average, biomass at stations 2 and 3 was about 25 times higher than at station 1 in both 1987 and 1988 (Figures 20 and 21). Cladocerans were much more important at the backwater stations and dominated at stations 2 and 3 in 1987 and again at station 2 in 1988. Copepods dominated station 3 in 1988. This shift in major group dominance at station 3 was the combined result of higher copepod biomass and lower cladoceran biomass in 1988. The shift in the zooplankton community dominant in 1988 coincided with a shift in phytoplankton community structure. More detailed analysis of both the zooplankton and the phytoplankton communities would be necessary to establish any causal link between these shifts.

Year-to-year variation in total community biomass was small at stations 1 (200-330 ug L^{-1}) and 2 (5250-5500 ug L^{-1}). The seasonal means for station 3 in 1987 and 1988 are not directly comparable because no early September sample was collected in the second year. Rotifers never accounted for a significant portion of total biomass at any of the stations. No consistent pattern of seasonal biomass fluctuation was evident at any of the stations.

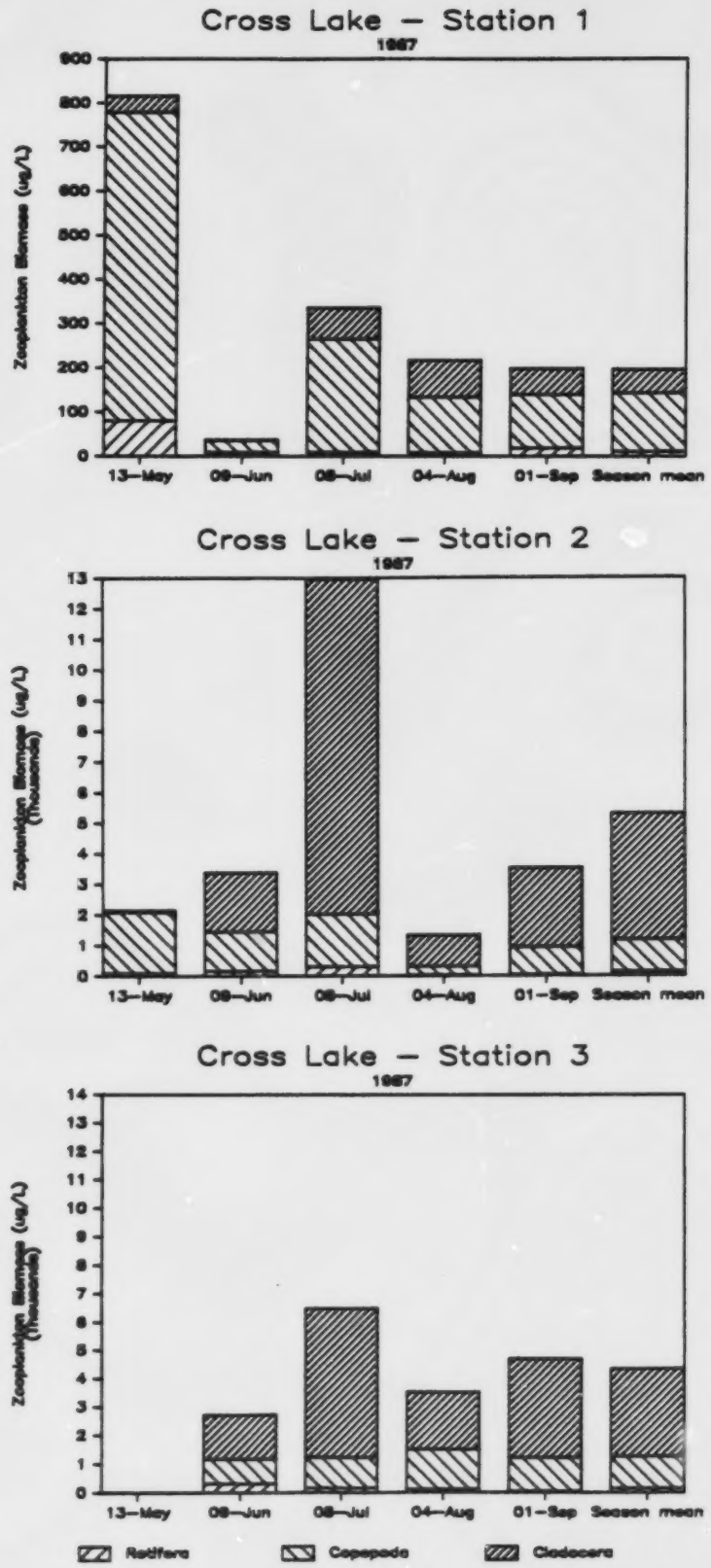

Figure 20. Distribution of zooplankton biomass among the major taxonomic groups in Cross Lake in the summer of 1987. Season mean excludes the May sample.

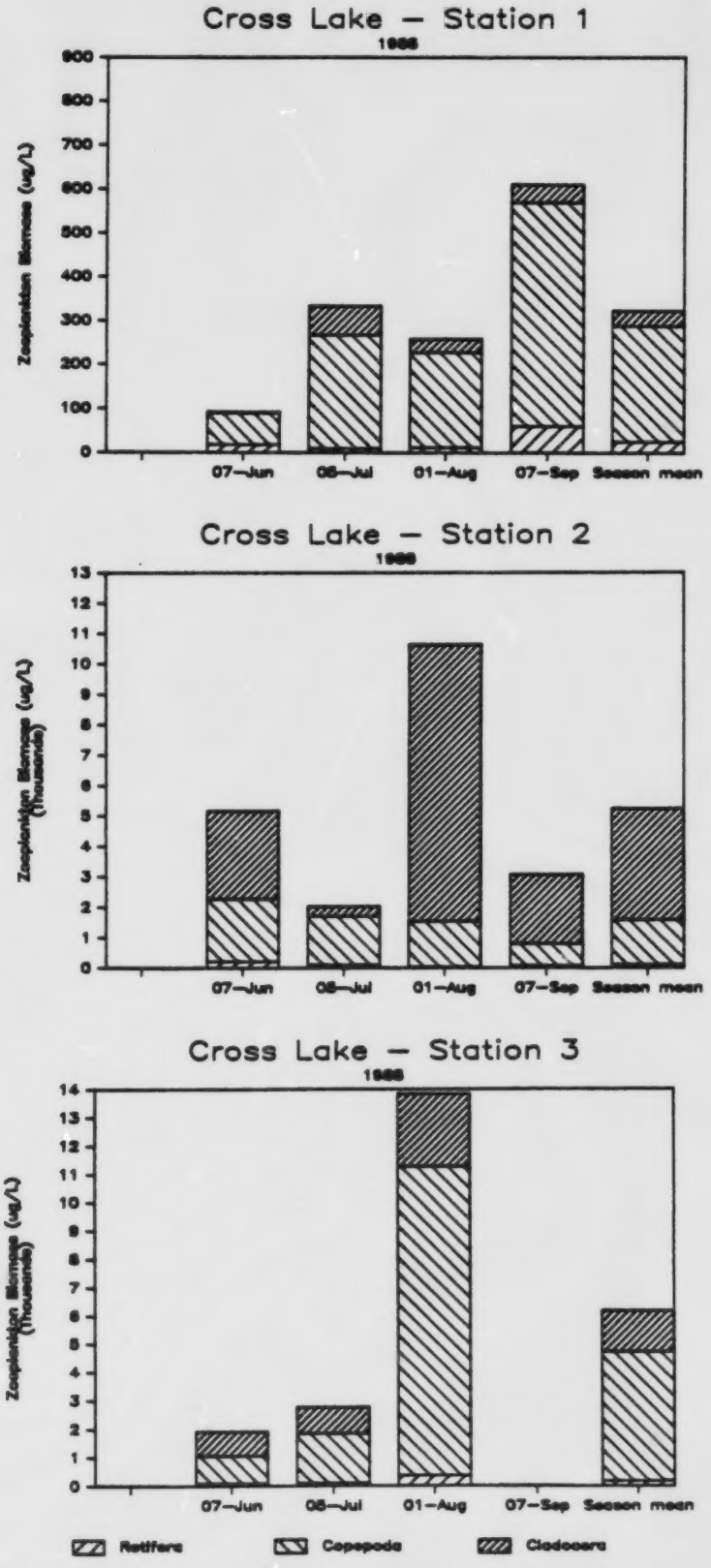

Figure 21. Distribution of zooplankton biomass among the major taxonomic groups in Cross Lake in the summer of 1988.

The higher zooplankton biomass at the backwater stations is generally consistent with the occurrence of higher phyotplankton standing stocks there. However, the absence of large year-to-year variation corresponding to that of the phytoplankton suggests that some other regulating factor is acting as well. Much of the phytoplankton contributing to these high standing crops, and particularly filamentous blue-greens like Anabaena sp., represent a poor direct source of food to the zooplankton.

5.2 Sipiwesk Lake

5.2.1 Water Quality

5.2.1.1 Spatial and Annual Variation

Station 1, the backwater station in Mud Bay, generally supported higher nutrient concentrations than the mainstem stations in both 1986 and 1987 (Table 10). These differences were particularly evident in TDN (40% higher), suspended N (78% higher), suspended P (26% higher), DOC (85% higher), suspended C (45% higher), and SrSi (3.6 times higher). TDP was about the same at the three stations in 1986 but was 63% higher at station 1 in 1987.

Concentrations of anions and cations, and particularly Cl^-, SO_4^{2+}, and Na^+, were lower at the backwater station than on the mainstem in both years (Table 11). The backwater station also was less transparent (lower Secchi), had higher turbidity and higher suspended sediment concentrations (2.4 times higher) than stations 2 and 3 (Table 12). Station 1 also was very highly coloured (3-5x higher) compared to the mainstem stations (Table 12).

5.2.1.2 Comparison with 1972-73

Examination of changes since the LWCNR study must be restricted to the mainstem stations since no backwater station was included in the initial study.

Table 10. Comparison of seasonal mean nutrient concentrations in Sipiwesk Lake before and after Lake Winnipeg regulation.

Station		1972 1'	1973 1'	1986 1	1986 2	1986 3	1987 1	1987 2	1987 3
NO_3-N	(ug L^{-1})	20	2	4	10	8	9	8	2
NO_2-N				<1	<1	<1	2	<1	<1
NH_3-N				27	23	23	22	20	32
TDN		400	349	510	397	360	542	360	368
Susp N		70	80	103	56	58	136	79	75
TDP	(ug L^{-1})	22	15	23	22	22	22	13	14
Susp P		16	14	15	11	11	19	14	14
DIC	(umole L^{-1})	1351	1842	1893	2117	2140	1806	1922	1852
DOC	(umole L^{-1})	575	508	1187	617	630	1174	658	654
Susp C	(ug L^{-1})	770	713	737	493	520	860	622	562
SrSi	(mg L^{-1})	0.70	0.71				2.09	0.57	0.58

Data sources
1972 Cleugh (1974), August 21-22
1973 Cleugh (1974), June 13 to September 26
1986 this study, June 9 to August 19
1987 this study, May 13 to September 1

Table 11. Comparison of seasonal mean pH and concentrations (mg L^{-1}) of anions, cations, and metals in Sipiwesk Lake before and after Lake Winnipeg regulation.

Station	1972 1'	1972a	1973 1'	1973a	1986 1	1986 2	1986 3	1987 1	1987 2	1987 3
Anions										
Cl^-	18	17.1	18.0	16.8	7.0	12.0	12.0	1.9	13.2	13.1
SO_4^{2-}		25.3	24.4	27	12.6	21.8	20.3	2.8	22.5	23.6
Cations										
Ca^{2+}	30	33.0	30.0	36	28.6	26.7	26.9	26.6	27.4	27.4
Mg^{2+}	12.2		10.7		9.8	10.3	10.1	8.0	11.1	11.0
Na^+	13.9	15	15.0	15.7	8.3	11.7	11.0	3.4	13.0	12.9
K^+	2.42	2.3	2.43	2.3	<5.0	<5.0	<5.0	1.14	2.02	2.00
pH										
lab	8.3	8.1	8.27	8.2	8.12	8.10	8.15	8.07	8.15	8.16
field					7.8	7.7	7.7	7.9	7.9	7.8
Metals										
Fe	0.18	0.15	0.09	<0.04	0.34	0.22	0.24	0.43	0.20	0.21
As								<0.001	<0.001	<0.001
Cd								<0.001	<0.001	<0.001
Cu		0.002		<0.002				<0.02	<0.01	<0.01
Zn		0.007		<0.001				<0.01	<0.01	<0.01
Pb		<0.006		<0.005				<0.005	<0.005	<0.005
Ni								<0.005	<0.005	<0.005
Mn		<0.012	<0.02	<0.009				<0.03	<0.02	<0.02

Data sources
1972 Cleugh (1974), August 21-22
1972a Morrelli (1974), July 11 to September 27
1973 Cleugh (1974), June 13 to September 26
1973a Morrelli (1974), July 10 and September 10
1986 this study, June 9 to August 19
1987 this study, May 13 to September 1

Table 12. Comparison of seasonal mean transparency, turbidity, dissolved and suspended solids concentrations, and colour in Sipiwesk Lake before and after Lake Winnipeg regulation.

Station	1972 1'	1972a	1973 1'	1973a	1986 1	1986 2	1986 3	1987 1	1987 2	1987 3
Secchi (m)	0.5		0.6		0.57	0.6	0.54	0.49	0.64	0.7
Turbidity (NTU)		23		3.8	9.7	6.7	5.8	14.0	6.9	7.3
TR (mg L^{-1})								172.5	200.0	202.5
NFR	20	18.8	10					7.3	2.8	3.3
TDS	180		194		180.0	166.7	173.3	164.0	190.0	188.0
Conductivity (uS cm^{-1})										
Lab (Ward)		296		313	235	253	243	189	270	266
Field	289		288		212	298	304	204	296	290
Calculated								208	314	313
Lab (DFO)								184	268	267
Colour (true)		23		15	30.0	8.3	10.0	44.0	8.0	7.0

Data sources
1972 Cleugh (1974), August 21-22
1972a Morrelli (1974), July 11 to September 27
1973 Cleugh (1974), June 13 to September 26
1973a Morrelli (1974), July 10 and September 10
1986 this study, June 9 to August 19
1987 this study, May 13 to September 1

Concentrations of nutrients in the dissolved phase (NO_3-N, TDN, TDP, DIC, DOC) in 1986-87 were generally within the range measured in 1972-73 (Table 10). Suspended C levels were lower in both years (by 32% in 1986 and 20% in 1987). Suspended P levels were at the lower end of the range measured in the LWCNR study. Suspended N concentrations were 24% lower in 1986 but in 1987 were comparable to levels measured in 1972-73.

Concentrations of all anions and cations were lower in 1986-87 than in 1972-73 (Table 11). Chloride was 28% lower, SO_4^{2+} was 14% lower, Mg^{2+} was 7% lower and Ca^{2+}, Na^{+}, and K^{+} were 15-18% lower. Iron was the only metal for which concentrations were consistently measurable and concentrations appear to have increased, as noted for most of the study sites. Again, this increase is attributed to the change in analytical method.

Water transparency and turbidity in 1986-87 were within the ranges measured in 1972-73 while suspended sediment concentrations were lower (Table 12). In 1972-73, NFR ranged from 10-20 mg L^{-1} compared to 2.8-7.3 mg L^{-1} in 1986-87. Similarly, dissolved solids concentrations in 1986-87 were at the low end of the range measured in 1972-73. Specific conductance measured in situ has not changed but the laboratory measurements averaged 15% lower in 1986-87. Colour was 55% lower in 1986-87 compared to 1972-73.

5.2.2 Phytoplankton Composition Biomass and Periodicity

5.2.2.1 Spatial and Annual Variation

Seasonal mean phytoplankton standing stocks at the mainstem stations (2 and 3) in Sipiwesk Lake were about the same, within 12% of their mean, in a given year (Figures 22 and 23). Mean standing biomass at the mainstem stations in 1988 was about 60% of mean biomass in 1987. As found in Cross Lake, seasonal mean phytoplankton biomass was higher at the backwater station in

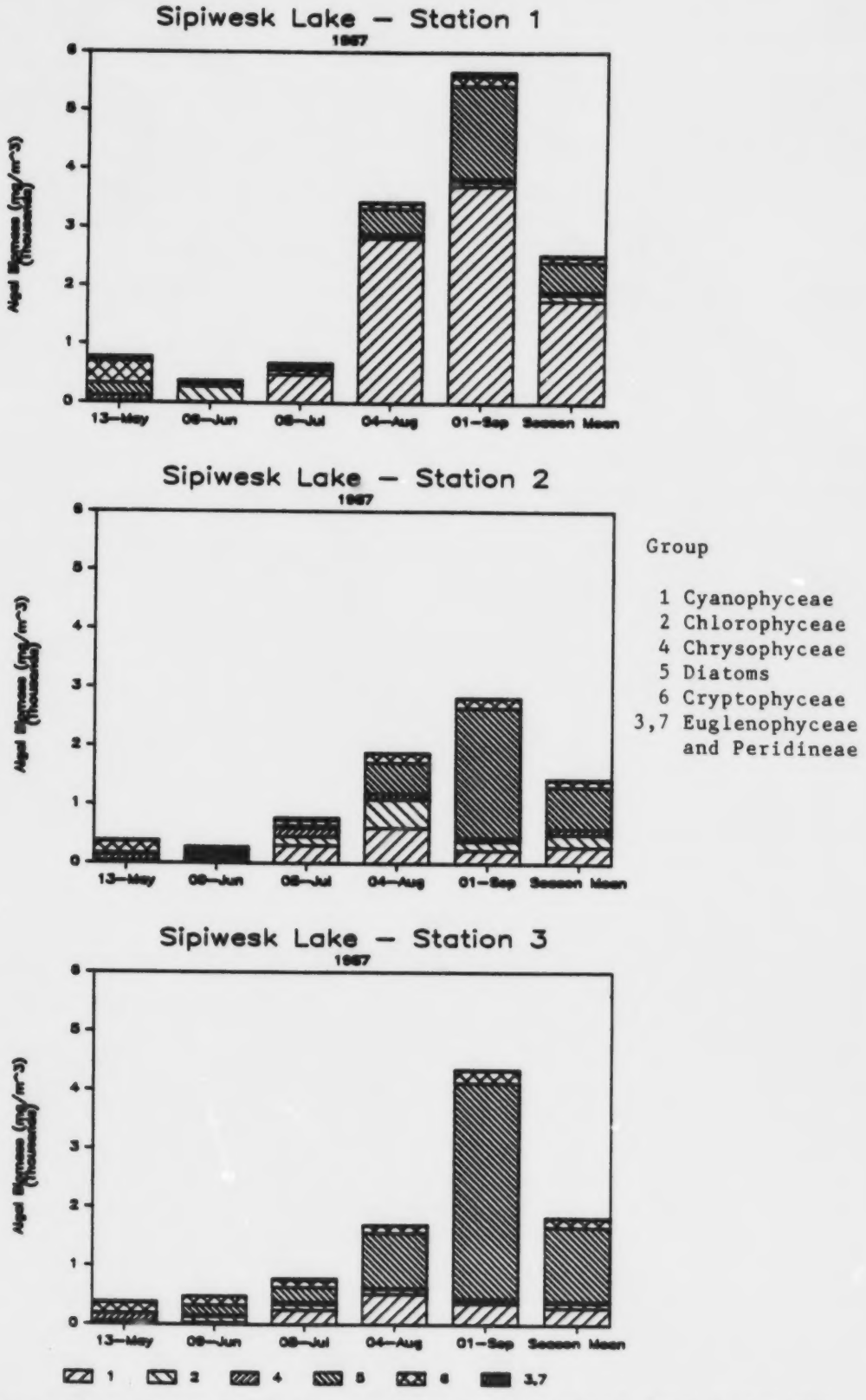

Figure 22. Algal biomass and taxonomic composition in Sipiwesk Lake during the summer of 1987. Season mean excludes the May sample.

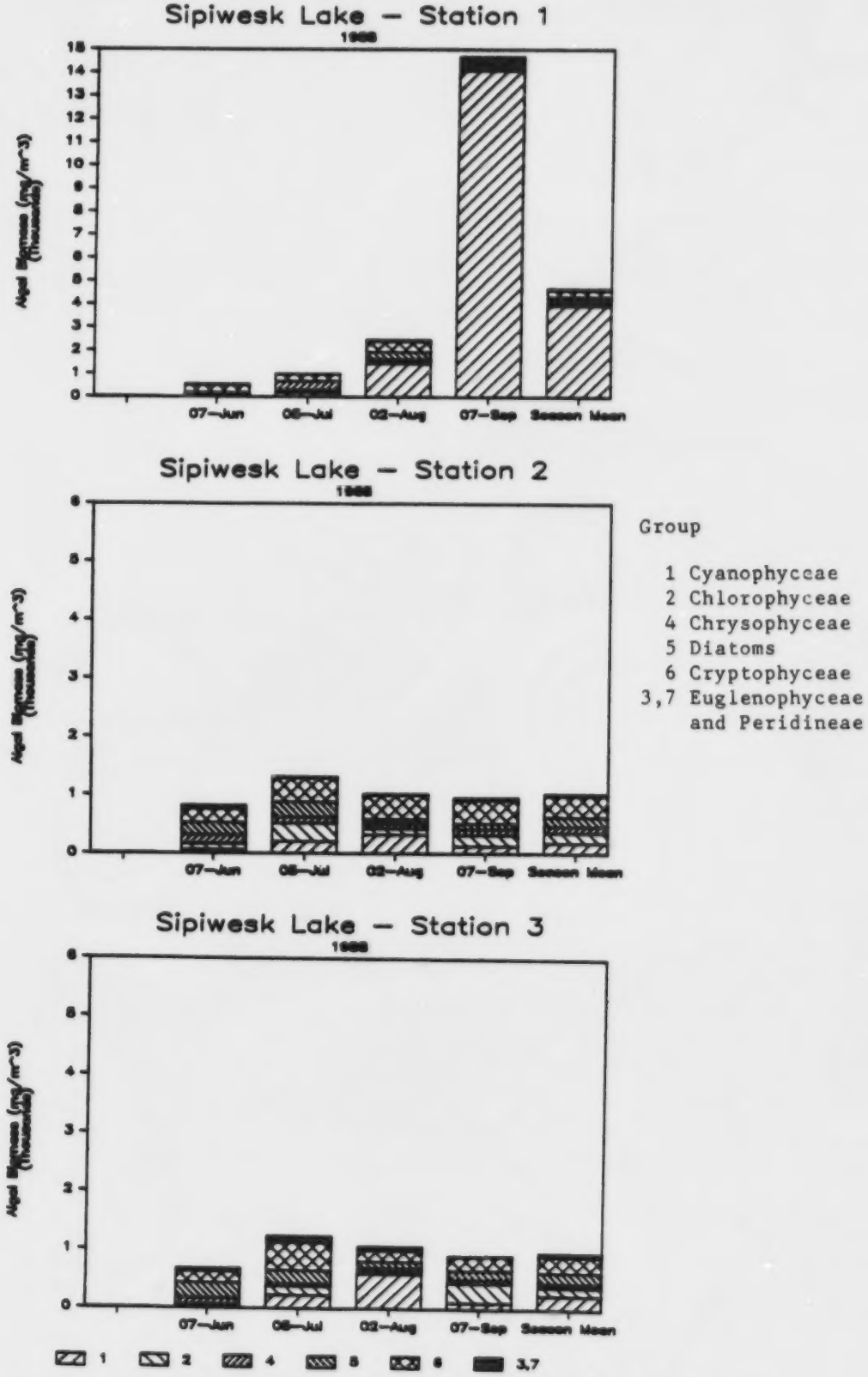

Figure 23. Algal biomass and taxonomic composition in Sipiwesk Lake in the summer of 1988.

Sipiwesk Lake than at the mainstem stations; by a factor of about 1.5 in 1987 and by a factor of 4.7 in 1988 (Figures 22 and 23). The differential in mean phytoplankton biomass between the mainstem and backwater stations in 1987 was of the same order as the differential in the seasonal mean concentrations of TDN and TDP (Table 10). The flushing rate in the backwater was undoubtedly lower as well. Water chemistry data are not yet available for 1988. The larger differential in biomass between the backwater and mainstem in 1988 than in 1987 was the combined result of lower biomass at the mainstem stations and an almost two-fold higher biomass in the backwater (Figures 22 and 23).

Cyanophytes dominated the phytoplankton community in the backwater much as in Cross Lake. In both years, biomass was highest during a late summer bloom and the greater biomass in 1988 was solely a result of higher levels during this period (Figures 22 and 23). Either the cyanophyte bloom was larger in 1988 or it may just have occurred earlier; sampling was discontinued before the bloom collapsed in both 1987 and 1988 and sampling was too infrequent to adequately describe the course of the bloom.

The phytoplankton communities at the mainstem stations were dominated by diatoms in 1987 which appeared in a late-summer bloom (Figures 22 and 23). A minor cyanophyte bloom also developed during mid-summer in both 1987 and 1988. Diatoms were a minor community component in 1988; no bloom had materialized by the termination of sampling in early September. The failure of the diatom bloom to develop during the sampling period in 1988 completely accounts for the lower seasonal mean biomass than in 1987. Seasonal mean phytoplankton standing stocks at the mainstem stations in Sipiwesk Lake were about the same as at the mainstem station in Cross lake in both 1987 and 1988 (Figures 17,18,22, and 23).

5.2.2.2 Comparison with 1972-73

Seasonal mean biomass at the mainstem stations in 1987-88, (994-1631 mg m-3; Figures 22 and 23) averaged about twice that in 1972-73 (440-885 mg m^{-3}; Figures 19 and 24). Community composition in 1972-73 was similar to that found in 1988. No diatom bloom developed in either 1972 or 1973 but the minor cyanophyte blooms were evident in both years. This lack of a diatom bloom in 1972-73 largely accounts for the lower seasonal mean biomass than in 1987-88. As in Cross Lake, the higher phytoplankton biomass in the present study could be a result of the lower Nelson River flows but might also be a result of differences in sample collection and/or analysis efficiency or in sampling location.

5.2.3 Zooplankton Composition Biomass and Periodicity

Zooplankton biomass at the backwater station was higher than at the mainstem stations in both 1987 and 1988 although the differential was much smaller than found in Cross Lake (Figures 25 and 26). Mean biomass at station 1 was 3.4 to 5 times higher than on the mainstem in 1987 but was just 1.9 times higher in 1988. The smaller differential in biomass between the backwater and mainstem in 1988 was the result of 25% lower biomass at station 1 and of biomasses at stations 2 and 3 that were 50-100% higher than in 1987.

The occurrence of higher zooplankton biomass at the backwater station is generally consistent with the higher phytoplankton standing stocks found there (Figures 22 and 23). However, year to year variations in phytoplankton biomass do not explain the interannual variation in zooplankton biomass at either the backwater or the mainstem stations. In both regions of the lake, seasonal mean zooplankton biomass was higher in the year in which the lower mean phytoplankton biomass was recorded. Some other regulatory factor must be

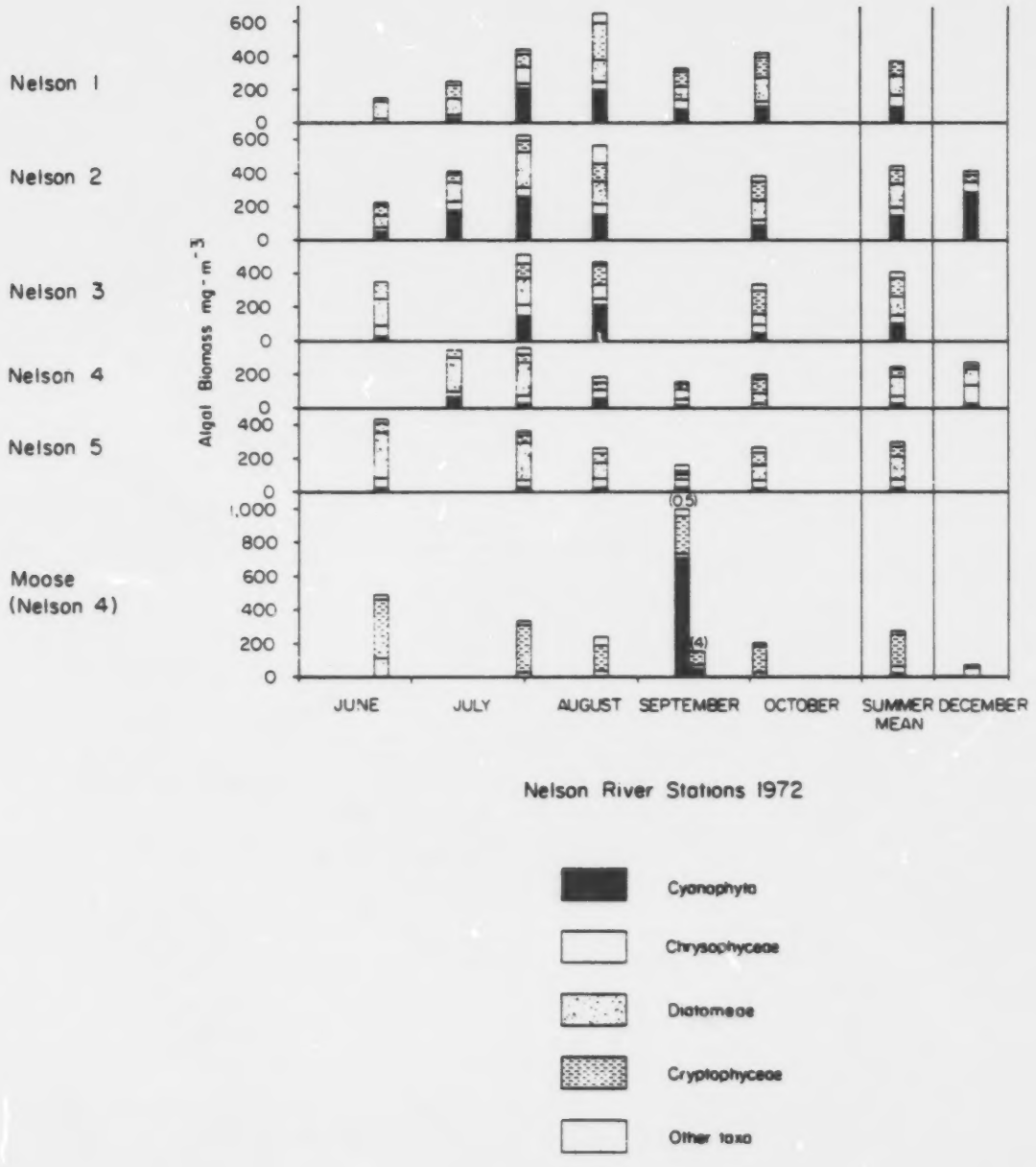

Figure 24. Algal biomass and taxonomic composition for the Nelson River during 1972.
From: Hecky and Harper (1974).

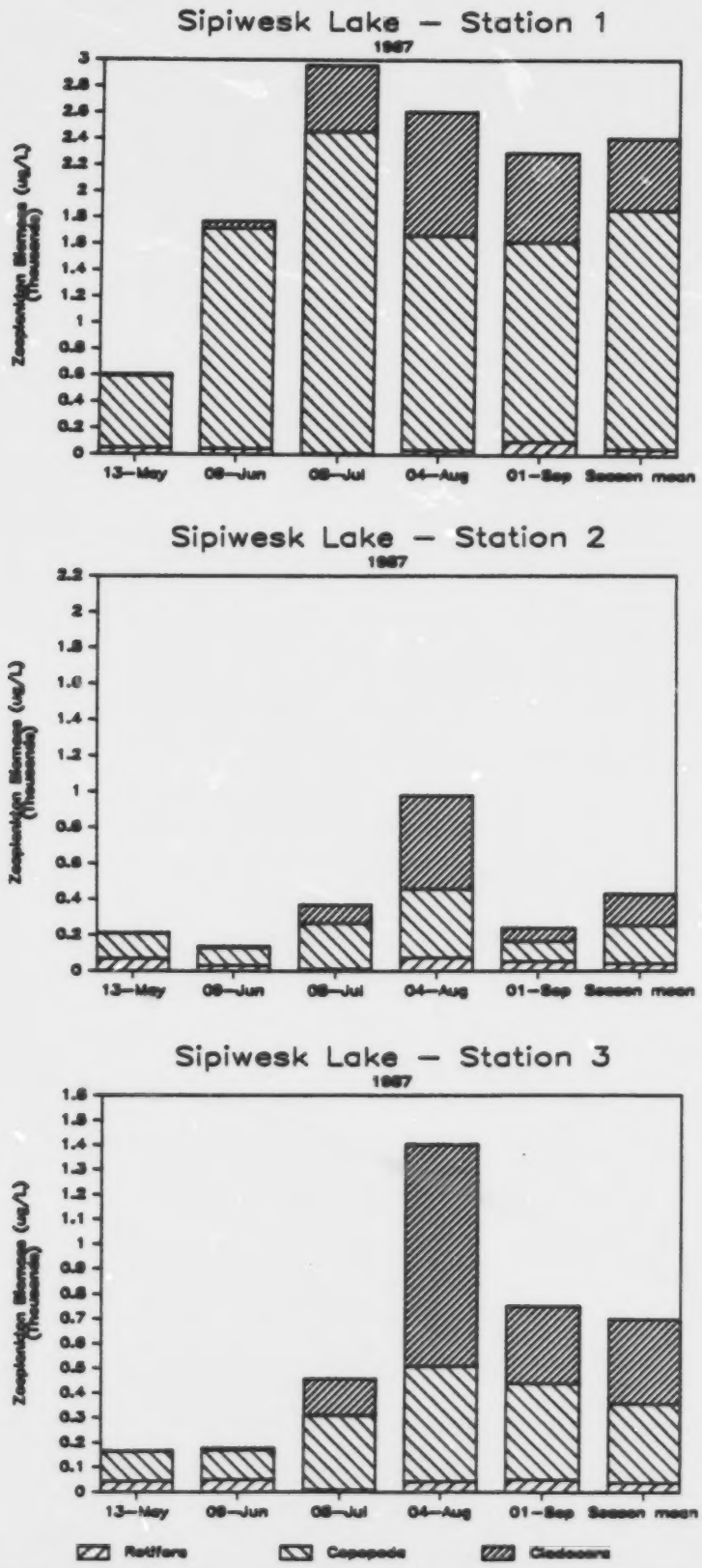

Figure 25. Distribution of zooplankton biomass among the major taxonomic groups in Sipiwesk Lake in 1987. Season mean excludes the May sample.

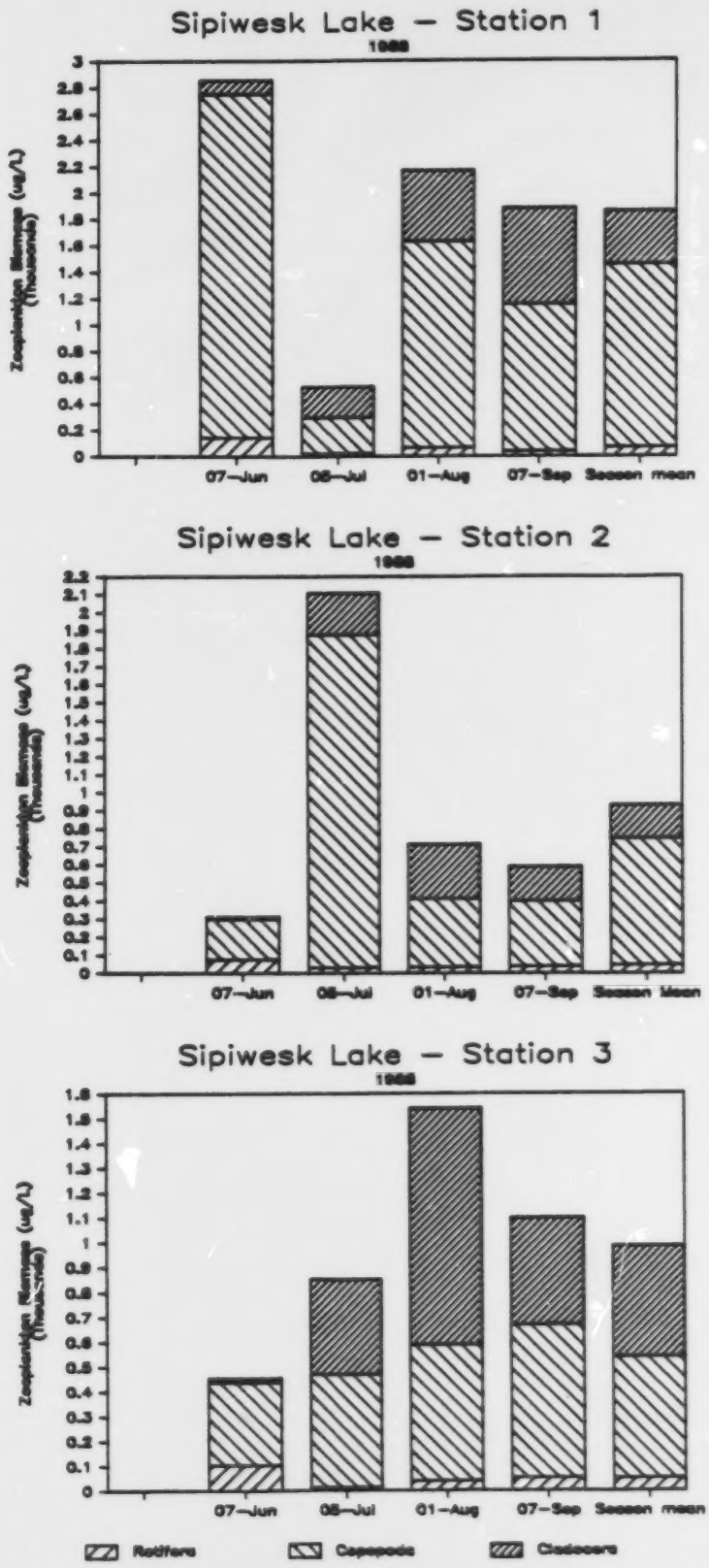

Figure 26. Distribution of zooplankton biomass among the major taxonomic groups in Sipiwesk Lake in the summer of 1988.

operating as well.

Copepods dominated station 1 in both 1987 and 1988 (Figures 25 and 26). Copepods and cladocerans were about equally represented at station 2 in 1987 and at station 3 in both years. The higher biomass at station 2 in 1988 was the product of higher copepod biomass and this group clearly dominated in 1988.

6.0 Limnological Changes in the Middle Nelson Lakes

6.1 Split Lake

6.1.1 Water Quality

6.1.1.1 Spatial and Annual Variability

There were few constants in the hydrologic regime of Split Lake during the current study. In 1986, diversion flows were reduced by about 25% in the June-August period compared with 1985 and 1987 (Water Survey of Canada 1985 and 1987) as a result of a 30% reduction of flow through the Notigi control structure (G. McCullough, Freshwater Institute, pers. comm.). In contrast, Nelson River flows at Kelsey in 1986 were particularly high; about a factor of 2 higher than the 1980-85 average for the June-August period (Water Survey of Canada 1980-85). Consequently, diversion flows averaged about 25% of Nelson River flows at Kelsey in June-August 1986. In 1987, Nelson River flows at Kelsey were just 40% of flows in 1986 with the result that the proportionate contribution of diversion flows to the total inflow to Split Lake was much higher in 1987; diversion flows in the June-August period were 84% of Nelson River flows during the June-August period (Water Survey of Canada 1986 and 1987). This variable proportionate contribution of the diversion can be seen in the water quality at mainstem station in Split Lake.

Major ion concentrations at station 3, situated in the plume of the Burntwood River, were consistently lower than at the other stations in the lake

(Table 13) reflecting the lower concentrations in the diversion than in the Nelson River (e.g., Tables 5 and 11) The difference was not as great in 1986 (anions, 20-35% lower; cations, 10-20% lower) as in 1987 (anions 85% lower; cations, 30-70% lower; Table 13). The greater difference in 1987 is consistent with the greater proportional contribution of diversion flow to total Nelson River flow than in 1986, as discussed above.

The highest major ion concentrations were consistently recorded at station 2, situated near the inflow of the Aiken River (Figure 6; Table 13). This presumably is a reflection of the ionic composition of the Aiken River. Anion concentrations were 8-20% higher and cation concentrations were 6-12% higher at station 2 than at station 1, located near the outflow of the lake, in 1986. In 1987, anion concentrations were 48-71% higher and cations were 11-43% higher than at station 1. The greater differential in 1987 was largely due to lower concentrations at station 1; major ion concentrations at station 2 were about the same in 1987 as in 1986. Major ion concentrations at station 4, situated in the Nelson River plume also were higher than at station 1 in 1987; anions by 34-44% and cations by 5-22%.

Few clear differences in nutrient concentrations among the stations can be identified although DIC concentrations were lowest at station 3 in both 1986 and 1987 (Table 14). DIC concentrations in lakes on the diversion averaged less than 50% of concentrations in lakes on the Upper Nelson in both 1986 and 1987 (Tables 7, 10, and 14).

Station 3 consistently had the lowest transparency, lowest dissolved solids concentrations and specific conductance, and the highest colour (Table 15). Again the differential was smaller in 1986 (Secchi 10% lower, TDS and conductivity 15% lower, colour 28% higher than at station 1) than in 1987 (secchi 50% lower, TDS 35% lower, field conductivity 44% lower, colour 53%

Table 13. Comparison of seasonal mean pH and concentrations (mg L^{-1}) of anions, cations, and metals in Split Lake before and after Lake Winnipeg regulation and Churchill River diversion.

Station	1972 2	1972 3	1972a	1973 2	1973a	1986 1	1986 2	1986 3	1987 1	1987 2	1987 3	1987 4
Anions												
Cl^-	17	16	14.6	17.1	14	12	13	8	7.4	11.7	1.3	9.9
SO_4^{2-}	23	21	22.0	23.5	22	20	24	17	11.9	20.4	2.7	17.1
Cations												
Ca^{2+}	26.7	26.6	26.3	28.7	35	26.9	28.6	25.2	22.5	26.6	16.1	24.5
Mg^{2+}	10.7	10.2		10.3		10.3	11.1	9.1	8.3	10.5	5.2	9.4
Na^+	12.7	12.1	13.1	14.3	13	11.3	12.6	9.2	8.2	11.7	3.1	10.0
K^+	2.30	2.23	1.9	2.29	2.1	<5	<5	<5	1.67	1.85	1.21	1.75
pH												
lab	8.2	8.2	7.9	8.3	8.1	8.22	8.17	8.12	8.11	8.17	8.03	8.14
field						7.8	7.8	7.5	7.9	7.7	7.6	7.8
Metals												
Fe	0.15	0.15	0.11	0.06	<0.03	0.38	0.29	0.37	0.39	0.27	0.77	0.34
As									<0.001	<0.001	<0.001	<0.001
Cd	0.008	<0.001							<0.001	<0.001	<0.001	<0.001
Cu	0.027	0.051	0.006		0.004				<0.01	<0.01	<0.01	<0.01
Zn	0.007	0.009	0.006		0.004				<0.01	<0.01	<0.01	<0.01
Pb	<0.002	<0.002	<0.007		<0.004				<0.005	<0.005	<0.005	<0.005
Ni									<0.005	<0.005	<0.005	<0.005
Mn	0.04	0.03	<0.009	<0.02	<0.009				<0.02	<0.02	<0.03	<0.02

Data sources
1972 Cleugh (1974): Station 2, May 30 to September 12; Station 3, June 28 to September 12; Cd, Cu, Zn, and Pb, September 12 only
1972a Morrelli (1974), July 13 to September 6
1973 Cleugh (1974), June 13 to September 26
1973a Morrelli (1974), July 10 and September 10
1986 this study, June 10 to August 17
1987 this study, May 13 to August 31

Table 14. Comparison of seasonal mean nutrient concentrations in Split Lake before and after Lake Winnipeg regulation and Churchill River diversion.

Station		1972		1973	1986			1987			
		2	3	2	1	2	3	1	2	3	4
NO_3-N	(ug L^{-1})	15	12	7	4	9	3	2	4	3	4
NO_2-N					<1	<1	<1	<1	<1	<1	<1
NH_3-N					27	27	27	18	18	24	22
TDN		438	347	318	350	367	380	340	354	320	350
Susp N		69	82	83	62	60	69	80	76	73	65
TDP	(ug L^{-1})	19	22	18	20	19	20	14	13	19	14
Susp P		17	20	14	14	13	16	18	13	22	13
DIC	(umole L^{-1})	602	1567	1762	1980	1983	1620	1490	1854	1154	1704
DOC	(umole L^{-1})	548	599	660	657	677	793	664	680	644	664
Susp C	(ug L^{-1})	827	886	675	510	533	603	750	620	796	545
SrSi	(mg L^{-1})	0.78	0.93	0.74				0.61	0.48	0.83	0.53

Data sources
1972 Cleugh (1974): Station 2, May 30 to September 12; Station 3, June 28 to September 12
1973 Cleugh (1974), June 13 to September 26
1986 this study, June 10 to August 17
1987 this study, May 13 to August 31

Table 15. Comparison of seasonal mean transparency, turbidity, dissolved and suspended solids concentrations, and colour in Split Lake before and after Lake Winnipeg regulation and Churchill River diversion.

Station	1972		1972a	1973a	1973	1986			1987			
	2	3			2	1	2	3	1	2	3	4
Secchi (m)	0.5	0.3			0.6	0.55	0.55	0.5	0.42	0.69	0.27	0.51
Turbidity (NTU)			28	8.4		10.8	8.7	10.7	11.8	7.0	18.0	8.1
TR (mg L^{-1})									165.0	195.0	120.0	180.0
NFR	18	22	23.1		10				5.8	3.0	10.0	6.5
TDS	158	164			182	166.7	176.7	146.7	144.8	184.0	107.6	166.0
Conductivity (uS cm^{-1})												
Lab (Ward)			266	277		253	271	222	204	258	124	269
Field	254	249			278	263	290	239	209	270	127	198
Calculated									231	293	137	261
Lab (DFO)									197	250	120	226
Colour (true)			33	25		11.7	11.7	15.0	13.0	11.0	19.0	13.2

Data sources
1972 Cleugh (1974): Station 2, May 30 to September 12; Station 3, June 28 to September 12
1972a Morrelli (1974), July 13 to September 6
1973 Cleugh (1974), June 13 to September 26
1973a Morrelli (1974), July 10 and September 10
1986 this study, June 10 to August 17
1987 this study, May 13 to August 31

higher). The highest transparency, lowest turbidity, highest TDS and conductivity, and lowest colour were consistently recorded at station 2.

6.1.1.2 Comparison with 1972-73

Examination of changes in water quality in Split Lake will be limited to changes at station 1 since that is the only area of the lake which was sampled both in the present study and in the LWCNR study.

Major ion concentrations in 1986 were at the low end of the ranges measured in 1972-73 (Table 13). Concentrations were much lower in 1987 than in 1972-73. Again, this may be a product of the high proportionate contribution of the diversion to Split Lake inflows in 1987. Anion concentrations in 1987 were 40-50% lower than the lowest mean concentration measured in 1972-73 and cations were 12-32% lower than the lowest pre-development values. With the exception of NO_3-N, which was 65-85% lower in the present study, concentrations of nutrients in the dissolved fraction in 1986-87 were at or near that measured in 1972 (Table 14). Concentrations of C,N, and P in the suspended fraction were 20-40% lower in 1986 than in 1972 but were near the pre-development levels in 1987. Silica concentrations in 1987 were about half that measured in 1972.

Mean water transparency was 50% higher in 1986 than in 1972 and 40% higher in 1987 (Table 15). Levels of turbidity in 1986-87 were at the low end of the range measured in 1972-73. Suspended sediment concentrations (NFR) in 1987 were about half the lowest concentration measured in 1972-73. Dissolved solids concentrations and specific conductance in 1986 were comparable to levels measured in 1972-73 but were 12% and 25%, respectively, lower in 1987. Colour in 1986-87 averaged about 50% lower than the lowest values measured in 1972-73.

6.1.2 Phytoplankton Composition Biomass and Periodicity

6.1.2.1 Spatial and Annual Variation

The phytoplankton community at station 3 on Split Lake, located in the plume of the Churchill River diversion, was very similar to those in Rat and Threepoint lakes upstream on the Churchill River diversion. The community was dominated by diatoms which occurred in a spring-early summer bloom (Figures 27 and 28). Both maximum and seasonal mean biomass were comparable to that found in Rat and Threepoint Lakes and the maximum and mean were about the same in 1987 and 1988.

Diatoms dominated the samples collected from both stations 1 and 2 in 1987 but the pattern of fluctuation over the summer was very different from that seen at station 3 (Figures 27 and 28). Total biomass was higher in spring than in mid-summer but the peak levels attained were just 35-50% of the peak at station 3. Standing crops in July and early August were as high or higher than at station 3. Significant late summer diatom blooms, in excess of 30,000 mg m^{-3}, developed at both stations 1 and 2 and were responsible for the higher seasonal mean biomass at these stations than at station 3.

In 1988, the samples from stations 1 and 2 were distinguished by the lack of diatoms compared to 1987 (Figures 27 and 28). Cryptophytes, and particularly Rhodomonas minuta, dominated the samples and were more abundant in 1988 than in 1987. Biomasses in June, July, and early August were about the same as in 1987. Sampling started about a month later in 1988 and by this time there was little evidence that any significant spring bloom had developed. No late summer bloom had developed by the termination of sampling in early September. In the absence of the late bloom in 1988, seasonal mean biomass at stations 1 and 2 averaged just 12% of mean biomass in 1987. Without the diatom bloom in 1988, seasonal mean standing stocks at both stations 1 and 2 were

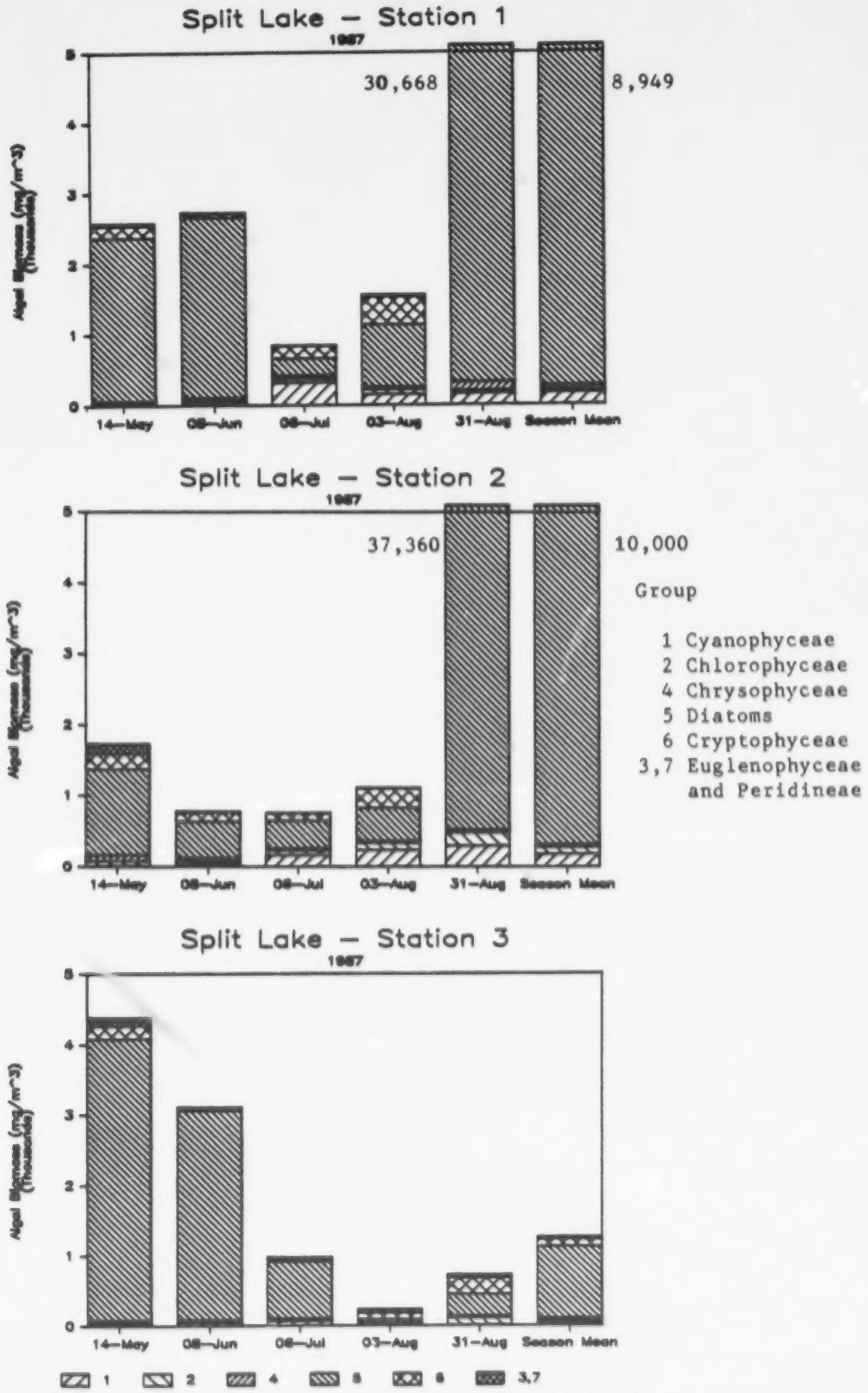

Figure 27. Algal biomass and taxonomic composition in Split Lake in the summer of 1987. Season mean excludes the May sample.

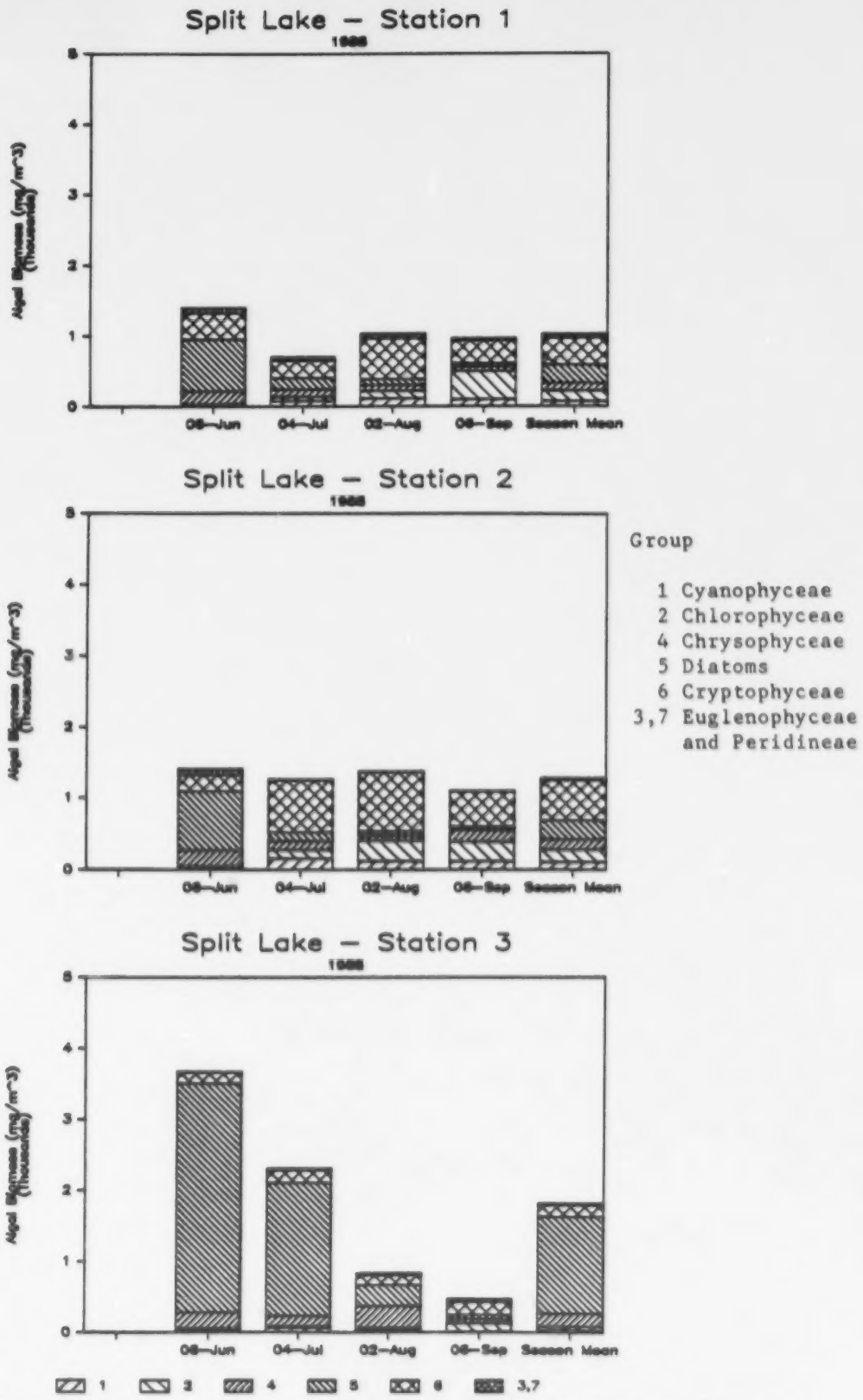

Figure 28. Algal biomass and taxonomic composition in Split Lake during the summer of 1988.

comparable to those at mainstem stations in both Cross and Sipiwesk lakes (Figures 17, 18, 22, 23, 27, and 28).

6.1.2.2 Comparison with 1972-73

Even without considering the autumn diatom pulse in 1987, mean phytoplankton biomasses at stations 1 and 2 were higher by 25-50% than found in 1972-73 (Figures 19, 24, 27, and 28). Major differences in community composition between the studies include the generally low importance of cyanophytes in 1987-88 compared to that found at (pre-development) station 2 in 1973 by Hecky and Harper (1974) and the greater importance, at least in 1987, of diatoms.

6.1.3 Zooplankton Composition Biomass and Periodicity

Zooplankton biomasses at stations 1 and 2 in Split Lake (Figures 29 and 30) were within the range found at mainstem stations in Cross and Sipiwesk Lake. Standing stocks at station 3, in the plume of the Burntwood River, averaged about 20% of the levels at stations 2 and 3 (Figures 29 and 30).

Seasonal mean zooplankton biomass at station 1 was about the same in 1987 and 1988, within about 12% of the between-year mean, with copepods dominating in both years. The seasonal occurrence of biomass at station 1 differed considerably in the two years however. In 1987, standing biomass was very low (50-100 ug L^{-1}) in May and early June and remained at a moderate level (300-400 ug L^{-1}) from early July to the end of August. In 1988, biomass was highest in early June (about 850 ug L^{-1}) and low in mid-summer (100-200 ug L^{-1}). This higher biomass in spring was evident to varying degrees at the other stations in Split Lake as well and was the product of high standing stocks of copepods and rotifers (Figures 29 and 30). Indeed, the early June sampling period in

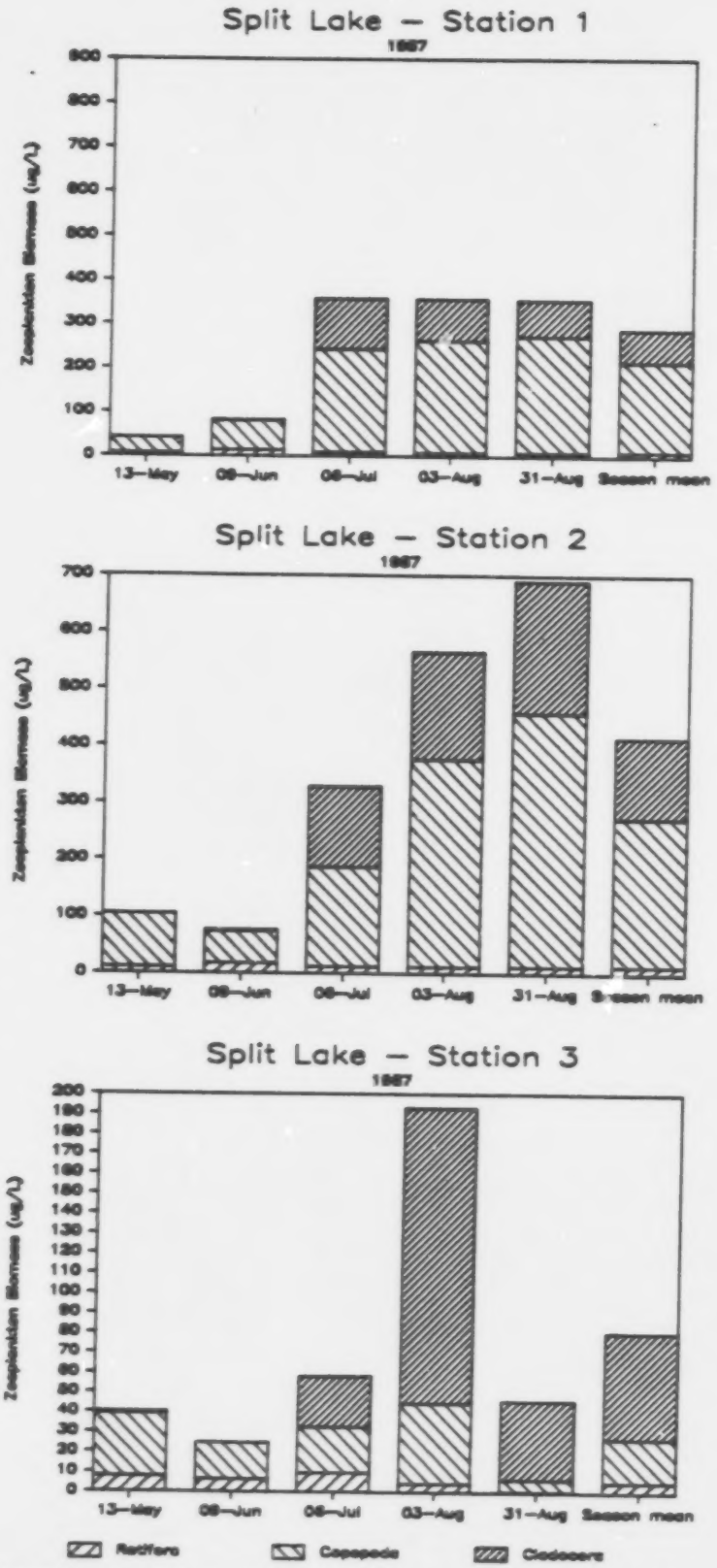

Figure 29. Distribution of zooplankton biomass among the major taxonomic groups in Split Lake in the summer of 1987. Season mean excludes the May sample.

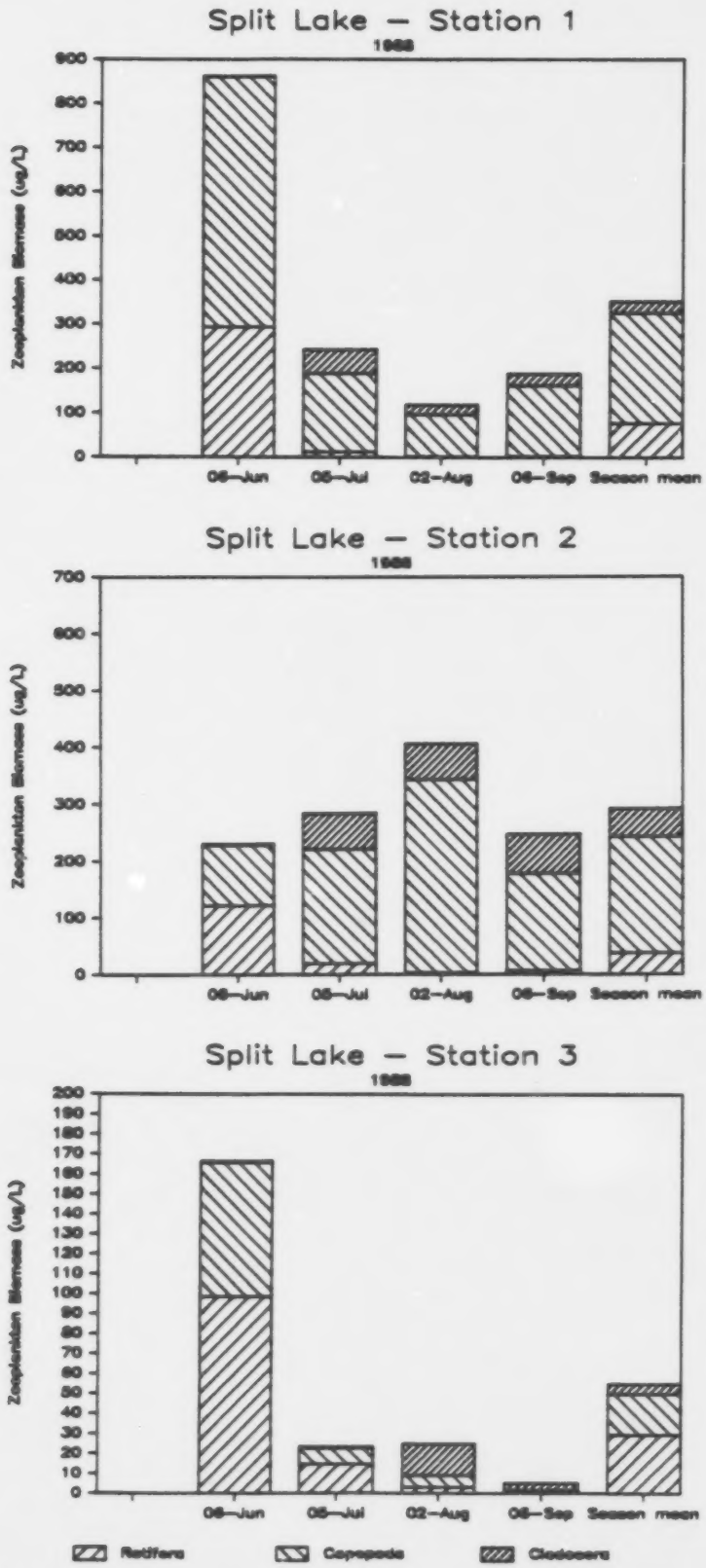

Figure 30. Distribution of zooplankton biomass among the major taxonomic groups in Split Lake in the summer of 1988.

1988 was the only time in the two seasons of study in which rotifers made a significant contribution to total zooplankton biomass. The timing of the seasonal maximum and the dominant zooplankton group varied even more at station 3 between the years than at station 1. In 1987, the seasonal maximum occurred in early August and was dominated by cladocerans compared with an early June maximum in 1988 that was dominated by rotifers (Figure 29 and 30). The seasonal pattern at station 2 was the least variable, with abundance generally highest in August and dominated by copepods in both years (Figures 29 and 30). However, seasonal mean biomass at station 2 varied more between years (30% lower in 1988) than at the other stations. This interannual variability in zooplankton abundance and composition was unrelated to phytoplankton community composition or biomass (Figures 27 and 28).

6.2 Stephens Lake

6.2.1 Water Quality

6.2.1.1 Moose Lake Area - Comparison with 1972-73

When first sampled in 1972-73, the Moose Lake (station 1) area of the reservoir was relatively clear, with a Secchi visibility of 1.9-2.2 m, and was comparatively nutrient rich for a site on the Nelson River (Cleugh 1974). Since the surveys in 1972-73, water quality in this area has become much more like that on the mainstem. Transparency has decreased to 0.6-0.9m, dissolved solids concentrations have increased about 15%, and concentrations of NO_3-N, TDN, TDP, and silica have all declined considerably (Tables 16 and 17). In particular, NO_3-N concentrations have declined more than 85% and TDP levels are 70-90% lower (Table 17). Silica concentrations were about 45% lower in 1987 than in 1972-73. Concentrations of nutrients in suspended matter were not markedly different in 1986-87 than in 1972-73. Dissolved inorganic and organic

Table 16. Comparison of seasonal mean transparency, turbidity, dissolved and suspended solids concentrations, and colour in Stephens Lake before and after Lake Winnipeg regulation and Churchill River diversion. Station 4 corresponds to station 1 in the current study and station 4' corresponds to station 3.

Station	1972 4	1972 4'	1972a	1973 4	1973 4'	1973a	1974	1986 1	1986 2	1986 3	1987 1	1987 2	1987 3
Secchi (m)	1.9	0.5		2.2	0.8			0.57	0.47	0.5	0.91	0.5	0.68
Turbidity (NTU)			15			5.2	4.5	13.5	13.3	13.3	3.8	12.4	7.8
TR (mg L^{-1})											170.0	160.0	150.0
NFR	<10	25	14.1	2	9						1.3	8.8	3.0
TDS	126	173		139	165			150.0	163.3	170.0	167.5	150.0	145.0
Conductivity (uS cm^{-1})													
Lab (Ward)			267			297	304	217	251	246	236	204	207
Field	204	249		230	268			200	248	250	233	211	209
Calculated											257	232	234
Lab (DFO)											225	197	198
Colour (true)			33			19	10	23.3	16.7	11.7	13.8	12.5	10.0

Data sources
1972 Cleugh (1974): Station 4, June 22 to September 12; Station 4', July 12 to September 12
1972a Morrelli (1974), July 6 to September 6
1973 Cleugh (1974): Stations 4 and 4', June 13 to September 26
1973a Morrelli (1974), June 4 to September 16
1974 Morrelli (1974), June 6 to September 11
1986 this study, June 10 to August 20
1987 this study, June 8 to August 31

Table 17. Comparison of seasonal mean nutrient concentrations in Stephens Lake before and after Lake Winnipeg regulation and Churchill River diversion. Station 4 corresponds to station 1, and station 4' corresponds to station 3.

Station	1972		1973		1986			1987		
	4	4'	4	4'	1	2	3	1	2	3
NO_3-N (ug L^{-1})	18	15	32	4	3	5	14	<1	2	2
NO_2-N					<1	<1	<1	<1	<1	<1
NH_3-N					23	20	17	23	23	23
TDN	554	387	550	336	343	367	363	313	345	340
Susp N	54	95	80	78	79	65	58	57	80	67
TDP (ug L^{-1})	53	23	73	18	15	22	20	8	16	16
Susp P	18	16	17	13	17	16	16	9	17	12
DIC (umole L^{-1})	1676	1582	1529	1393	1883	1737	1820	2083	1561	1604
DOC (umole L^{-1})	1037	667	875	668	763	670	663	723	670	618
Susp C (ug L^{-1})	555	782	1038	913	1087	577	507	558	695	503
SrSi (mg L^{-1})	1.70	1.04	1.46	0.79				0.86	0.67	0.65

Data sources
1972 Cleugh (1974): Station 4, June 22 to September 12; Station 4', July 12 to September 12
1973 Cleugh (1974): Stations 4 and 4', June 13 to September 26
1986 this study, June 10 to August 20
1987 this study, June 8 to August 31

carbon concentrations in 1986-87 also were at or near the 1972-73 levels. Concentrations of anions and cations are similarly unchanged (Table 18). Suspended solids concentrations (NFR) and specific conductance have not changed (Table 18).

6.2.1.2 Mainstem Stations - Comparison with 1972-73

No similar changes in water quality have occurred in the mainstem area of Stephens Lake which indicates that the changes observed in the Moose Lake area of the reservoir are more likely a result of the evolution of conditions in the backflooded area of the reservoir rather than representing an effect of additional system development. In particular, TDN concentrations at the mainstem stations were the same in 1986-87 as in 1972-73 and the ranges of NO_3-N and TDP concentrations in 1986-87 overlap the ranges measured in 1972-73 (Table 17). Similarly, concentrations of suspended N and P and of DIC and DOC remain about the same. Suspended C concentrations in 1986-87 averaged about 33% lower than in 1973-74 while silica concentrations are now about 28% lower. No clear differences in the concentrations of anions and cations are evident between 1972-73 and 1986-87 although the highest concentrations measured in 1986-87 were generally comparable to the lowest concentrations measured in 1972-73 (Table 18). As found at most sites, iron concentrations were higher in 1986-87 than in 1872-73 but this increase is attributed to the change in analytical methods (Table 18). Unlike the Moose Lake station, which has become less transparent in the past 13-14 years, levels of transparency, turbidity, suspended and dissolved solids concentrations, specific conductance, and colour measured at the mainstem stations in 1986-87 were within the range of values measured in 1972-73 (Table 16).

Table 18. Comparison of seasonal mean pH and concentrations (mg L^{-1}) of anions, cations, and metals in Stephens Lake before and after Lake Winnipeg regulation and Churchill River diversion. Station 4 corresponds to station 1 in the current study and station 4' corresponds to station 3.

	1972		1972a	1973		1973a	1974	1986			1987		
Station	4	4'		4	4'			1	2	3	1	2	3
Anions													
Cl^-	7	16	14.5	5.3	16.2	14	18	5	11	11	5.0	7.4	7.6
SO_4^{2-}	10	22	22.2	14.1	25.1	24	28	9	21	20	8.9	13.3	13.8
Cations													
Ca^{2+}	28.0	26.8	28.4	28.6	27.6	37	31	33.3	26.6	27.0	33.4	22.8	23.0
Mg^{2+}	8.2	10.2		8.2	9.9			7.7	10.1	10.0	8.0	8.3	8.2
Na^+	5.8	11.7	12.7	7.1	13.7	14	17	6.3	10.9	10.9	5.5	8.0	7.9
K^+	1.70	2.21	1.9	1.74	2.19	2.0	2.2	<5	<5	<5	1.22	1.62	1.60
pH													
lab	7.6	8.2	8.0	7.6	8.3	8.1	8.0	7.93	8.22	8.17	8.13	8.14	8.08
field								7.7	7.8	7.9	7.8	7.8	7.7
Metals													
Fe	0.18	0.14	0.04	0.18	0.08	<0.04	<0.04	0.28	0.43	0.38	0.17	0.52	0.34
As											<0.001	<0.001	<0.001
Cd	<0.001	0.002									<0.001	<0.001	<0.001
Cu	0.005	0.033	0.002			0.012	0.01				<0.01	<0.01	<0.01
Zn	0.003	0.007	0.009			<0.002	0.001				<0.01	<0.01	<0.01
Pb	0.002	<0.002	<0.004			<0.004	<0.005				<0.005	<0.005	<0.005
Ni											<0.005	<0.005	<0.005
Mn	0.03	0.03	<0.008	0.04	<0.02	<0.008	<0.01				<0.02	<0.02	<0.02

1972 Cleugh (1974): Station 4, June 22 to September 12; Station 4', July 12 to September 12; Cd, Cu, Zn, Pb, September 12 only
1972a Morrelll (1974), July 6 to September 6
1973 Cleugh (1974): Stations 4 and 4', June 13 to September 26
1973a Morrelll (1974), June 4 to September 16
1974 Morrelll (1974), June 6 to September 11
1986 this study, June 10 to August 20
1987 this study, June 8 to August 31

6.2.2 Phytoplankton Biomass and Periodicity

6.2.2.1 Spatial and Annual Variation

Phytoplankton community composition and biomass varied considerably among the stations in each year and between 1987 and 1988. In 1987, diatoms were the dominant constituents at all 3 stations but mean biomass ranged over an order of magnitude; from about 600 mg m^{-3} at station 1 to 6100 mg m^{-3} at station 2 with station 3 intermediate in this range (Figure 31). At stations 1 and 3, biomass was highest in early June compared with a late summer diatom pulse at station 2. The late peak at station 2 occurred during the same sampling interval as the late peaks in Split Lake (Figures 27 and 31).

In 1988, seasonal mean biomass was higher by a factor of 3.5 at station 1 was lower by a factor 4 at station 2 and was about the same at station 3 compared to 1987 (Figures 31 and 32). No single phytoplankton group dominated at all three stations in 1988. Chrysophytes followed by cyanophytes were most abundant at station 1 (Figure 32). Cryptophytes, cyanophytes, and diatoms, in decreasing order accounted for most of the biomass at station 2. Diatoms and, to a much lesser extent, cryptophytes were the major contributors to community biomass at station 3. No clear pattern of seasonal biomass fluctuation was evident at station 2 and biomass at station 3 was dominated by a diatom pulse in early August.

6.2.2.2 Comparison with 1972-73

Prior to development, the phytoplankton community at the Moose Lake station, which corresponds to station 1 in the present study, was distinctive from that found on the mainstem Nelson River. Cryptophytes dominated the samples in both 1972 and 1973 (Hecky and Harper 1974; Figures 19 and 24). In contrast, cryptophytes were not important contributors to community biomass on

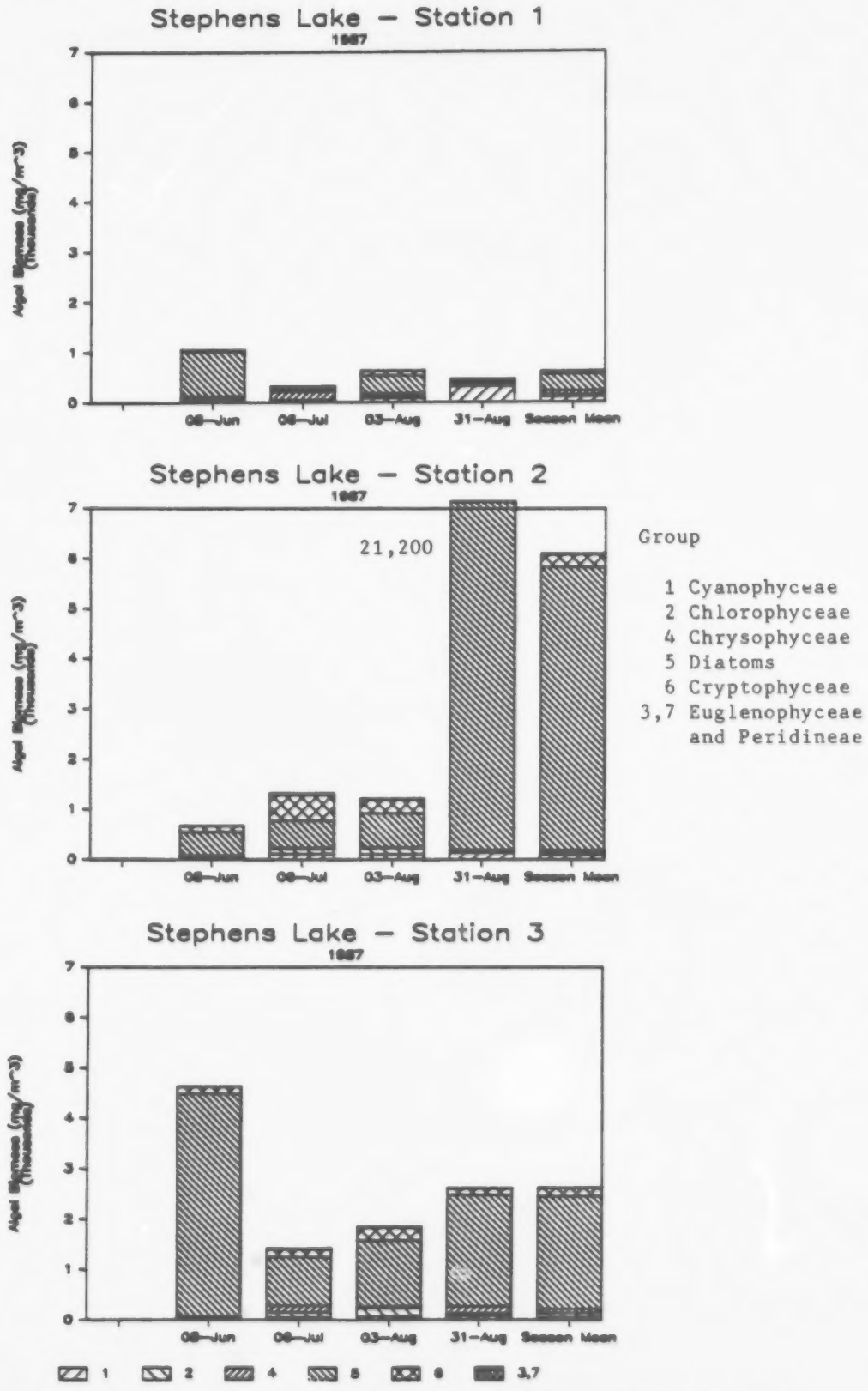

Figure 31. Algal biomass and taxonomic composition in Stephens Lake in 1987.

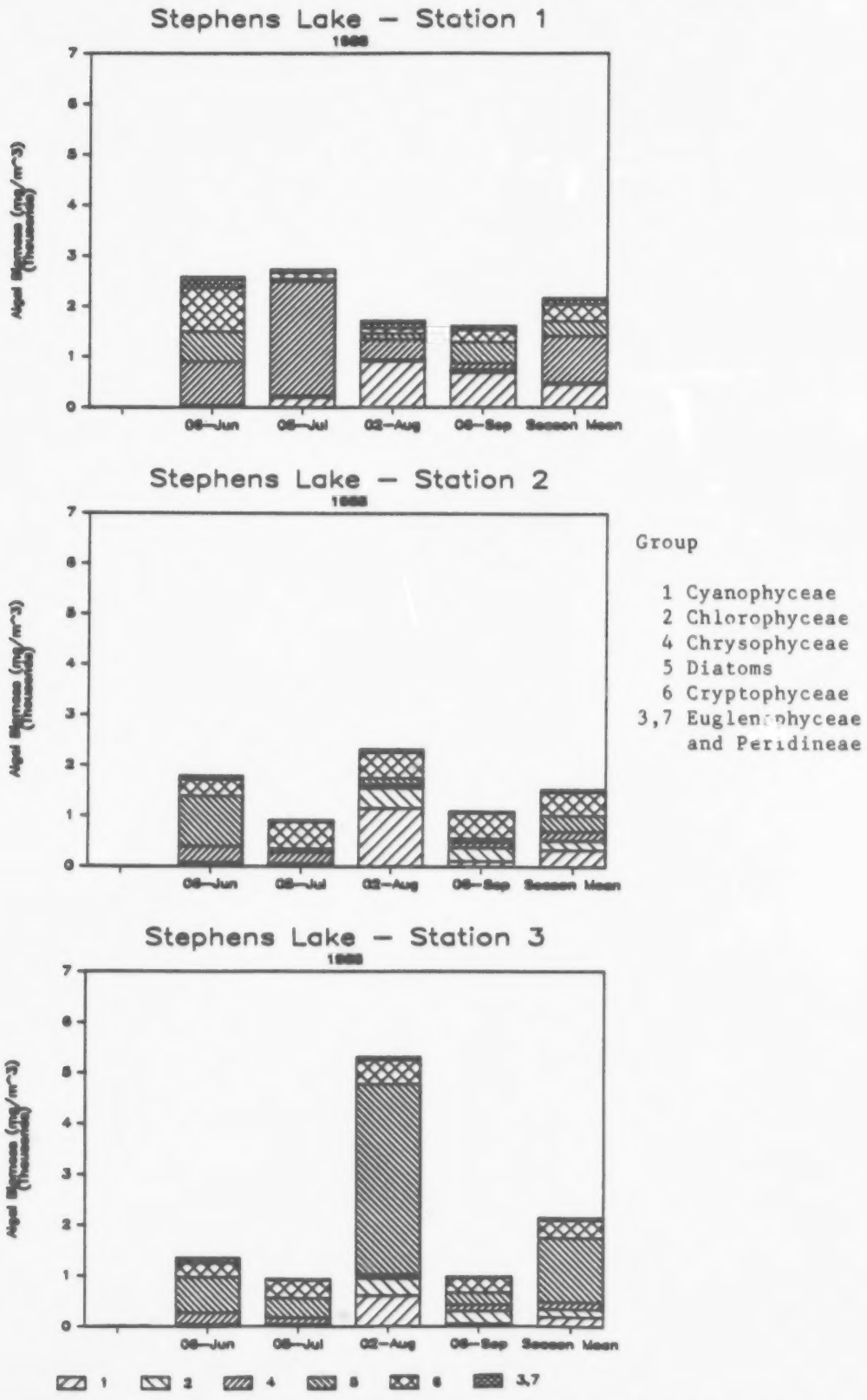

Figure 32. Algal biomass and taxonomic composition in Stephens Lake in 1988.

average in the present study and were dominant only in the early June sample in 1988 (Figures 31 and 32). As a result, community composition in the Moose Lake region of the reservoir also is no longer distinctive from that at the mainstem stations (Figure 31 and 32). Despite this change in community composition, the pattern of seasonal biomass fluctuation, highest in June and lowest in late summer, remains the same. The considerable year to year variation in mean biomass seen at station 1 in the present study also was present in 1972-73 and there is no clear difference in mean biomass between the present and the previous studies; mean biomass was 300-1300 mg m^{-3} in 1972-73 compared with 600-2150 mg m^{-3} in 1987-88.

The community composition found at the mainstem stations in 1987-88 was not notably different from that found in 1972-73. The major community constituents were the same overall and the community dominants varied as much between years then as observed in the present study (Figures 19, 24, 31, and 32). Summer mean biomass varied considerably between 1972 (about 250 mg m^{-3}) and 1973 (about 550 mg m^{-3}). Despite the considerable year to year variation in both studies, standing biomass in 1987-88 was clearly higher, by at least a factor of 2, than in 1972-73 (Figures 19,24, 31, and 32).

6.2.3 Zooplankton Composition Biomass and Periodicity

The zooplankton communities at the mainstem stations in Stephens Lake were the most depauperate of those sampled. Seasonal mean biomass at stations 2 and 3 ranged from 30 to 106 ug L^{-1} (Figures 33 and 34) compared with 200-330 at the mainstem station in Cross Lake, 430-986 at the mainstem stations in Sipiwesk Lake, and 281-383 at station 1 in Split Lake. The lower biomass was consistently recorded at station 2 and seasonal mean biomass at the mainstem stations in Stephens Lake varied less than 10% between 1987 and 1988. Copepods

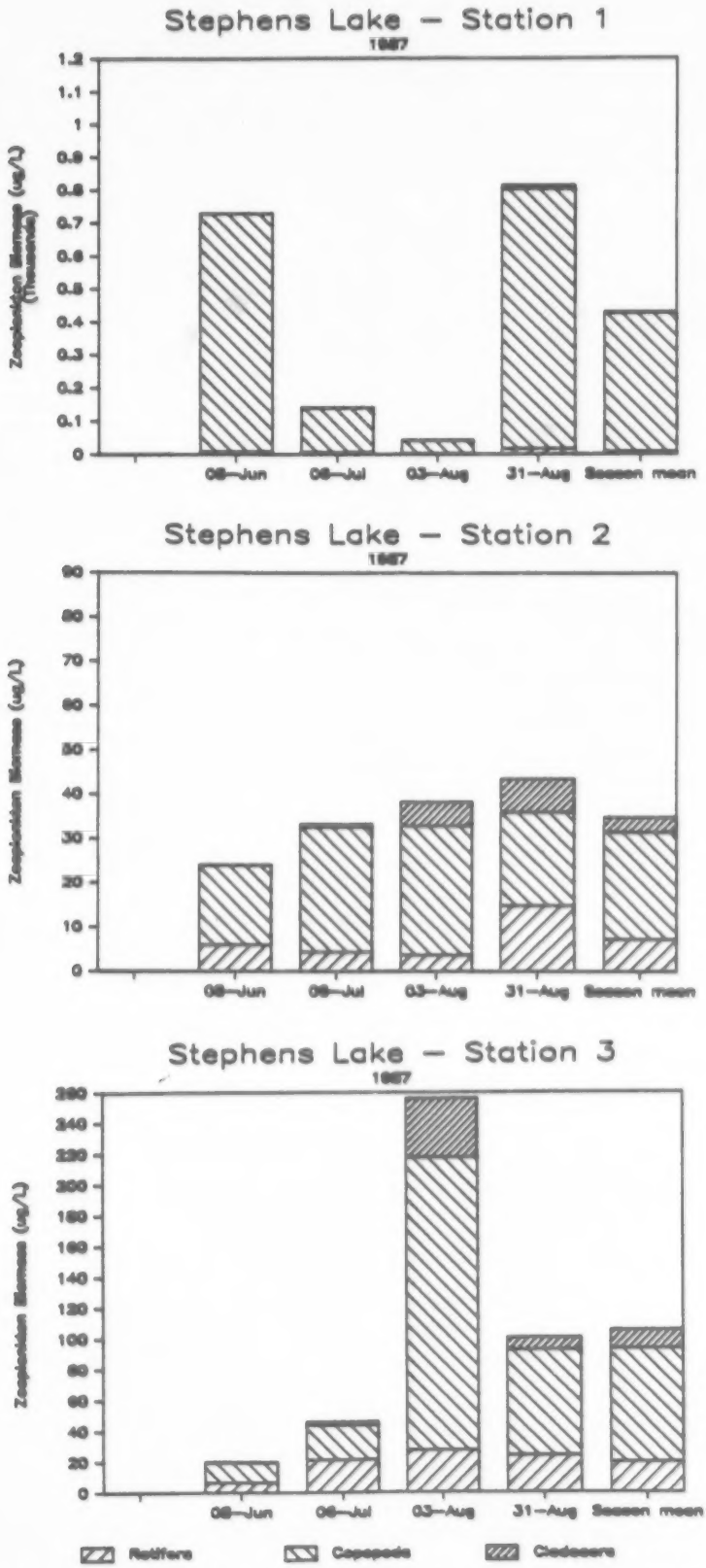

Figure 33. Distribution of zooplankton biomass among the major taxonomic groups in Stephens Lake in 1987.

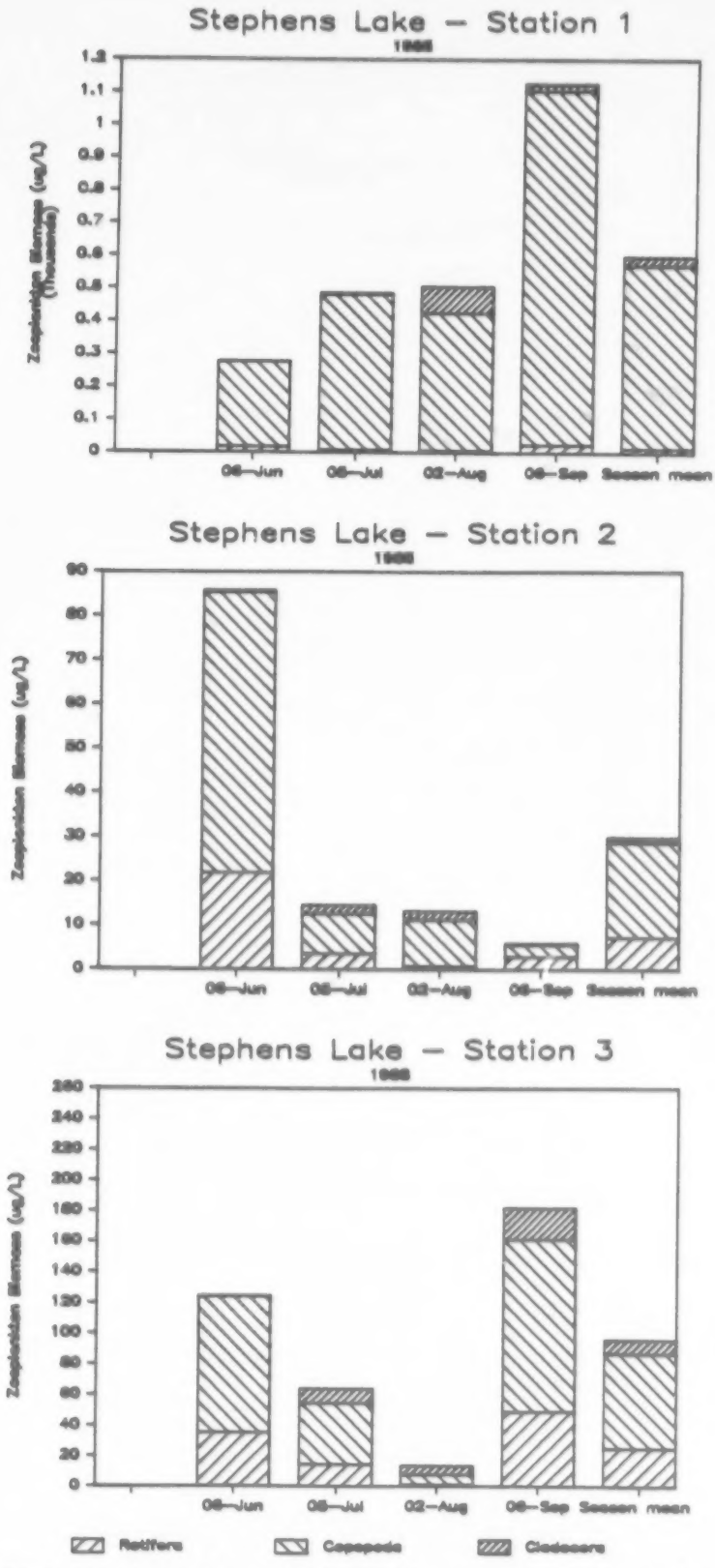

Figure 34. Distribution of zooplankton biomass among the major taxonomic groups in Stephens Lake in 1988.

were the dominant zooplankton group, accounting for 65-72% of mean biomass at both mainstem stations.

Following the trend found in the other lakes on the Nelson River, zooplankton biomass was markedly higher at the backwater station (1) than at the mainstem stations (Figures 33 and 34). At 353-430 ug L^{-1}, mean biomass at station 1 was about 4 times higher than at the stations 2 and 3 but was just comparable to that at the mainstem stations in the other lakes on the Nelson River. Copepods were the only important community component, accounting for 93-97% of mean total biomass.

Unlike the other lakes on the Nelson River, the higher zooplankton standing stocks at the backwater station occurred in the absence of higher phytoplankton standing stocks (Figures 31 and 32). With zooplankton and phytoplankton biomasses at station 1 comparable to those found at mainstem stations on the Nelson, it appears that the it is the low zooplankton biomass at stations 2 and 3 in Stephens Lake which require explanation. Higher grazing pressure by fish in the mainstem is unlikely given the generally turbid conditions in the reservoir (Table 16). A more probable cause is higher flushing rates on the mainstem.

7.0 Recommendations for Future Studies

1. Collection of phytoplankton samples from Rat, Threepoint, and Split lakes during the month of May to catch the spring diatom bloom.

2. Review of the phytoplankton sample analysis procedures used in the current study compared with the LWCNR study to determine if the apparent increases at the mainstem stations on the Nelson River are real or an artefact.

3. As a cost-saving measure, eliminate the analyses of metals. With the exception of iron and occasionally manganese, metals concentrations were below the limits of detection.

4. Identify and evaluate all other sources of pre- and post-development data for the study lakes.

5. Identify the Rat Lake zooplankton samples to species and convert the data collected by Patalas and Salki (1974) to make the datasets comparable.

6. Review other studies which have been or are currently being conducted in the area of the Nelson River and the CRD to identify sources of reference data useful for definition of natural limnological trends. This should permit better discrimination of changes due to the hydro-developments from changes due to natural variation.

7. Develop a computer database of all pre- and post-development data. This will facilitate more detailed comparisons of pre/post conditions (e.g., examination of changes in seasonal patterns as recommended below). One of the new generation of relational database managers like Paradox 3 or dBase IV would be most suitable for this task. This would make all of the data readily available to all of the members of the working group and would facilitate the exchange of data with the other groups working on the Northern Flood Agreement. Any detailed examination of change in a parameter requires such a database and past experience has shown that it is more efficient in the long run to establish a comprehensive database at the outset rather than to develop it in a haphazard manner during the course of the analysis.

8. Conduct an examination of changes in the seasonal variation in water quality parameters. The changes in seasonal mean values discussed in this report may be the result of general increases or decreases over the season or could be the result of a major change during part of the season. Any relationships between changes in water quality and the biotic changes may be clarified by such an examination.

9. Investigate methods of evaluating the significance of long-term variation in analytical laboratory performance.

8.0 References

Cleugh, T.R. 1974. Hydrographic survey of lakes on the Lower Churchill, and Rat-Burntwood rivers and reservoirs and lakes on the Nelson River. Lake Winnipeg, Churchill and Nelson Rivers Study Board, 1971-75. Tech. Rep. Append. 5, Vol. 2E. Queen's Printer, Winnipeg, Manitoba.

Driver, E.A., and K.H. Doan. 1972. Fisheries survey of Cross Lake (Nelson River), 1965. Manitoba Dept. Mines, Res., and Env. Mgmt., Research Branch MS Rep. 73-5, 17p.

Green, D.J. 1986. Summary of fish mercury data collected from lakes on the Rat-Burntwood and Nelson river systems, 1983-85. Manitoba Dept. Nat. Res., Fisheries Branch MS Report No. 86-06. 359p.

Hecky, R.E., and R.J. Harper. 1974. Phytoplankton and primary production of the lower Churchill lakes, Rat-Burntwood lakes, and Nelson River lakes and reservoirs. Lake Winnipeg, Churchill and Nelson Rivers Study Board, 1971-75. Tech. Rep. Append. 5, Vol. 2F. Queen's Printer, Winnipeg, Manitoba.

Koshinsky, G.D. 1974. The limnology-fisheries of the outlet lakes area: present conditions and implications of hydroelectric development. Lake Winnipeg, Churchill and Nelson Rivers Study Board, 1971-75. Tech. Rep. Append. 5, Vol. 2A. Queen's Printer, Winnipeg, Manitoba.

Livingstone, L. 1988. Summary of phytoplankton data for the Nelson River and Rat-Burntwood lakes, 1987. Manitoba Dept. Nat. Res., Fisheries Branch MS Rep. No. 88-04.

Morrelli, M. 1974. Results of the water sampling program in northern Manitoba, 1972-74. Lake Winnipeg, Churchill and Nelson Rivers Study Board, 1971-75. Tech. Rep. Append. 2, Vol. 2A. Queen's Printer, Winnipeg, Manitoba.

Patalas, K., and A. Salki. 1974. Crustacean plankton of lakes on the lower Churchill River and Rat-Burntwood river systems. Lake Winnipeg, Churchill and Nelson Rivers Study Board, 1971-75. Tech. Rep. Append. 5, Vol. 2G. Queen's Printer, Winnipeg, Manitoba.

Appendix 1. List of Manitoba Department of Natural Resources Fisheries Branch reports written to date on data collected from the Churchill-Nelson River Diversion under the Northern Flood Agreement Claim numbers 12 and 18. Documents are listed in chronological order of publication.

Year	Title
1984	Patalas, J.W. 1984. Fish population data from Sipiwesk, Split and Stephens lakes, 1983. Man. Dept. Nat. Res. Fish. Br. MS Report No. 84-24, 66pp.
	_____1984. Fish population data from Notigi, Wapisu, Threepoint and Footprint lakes, 1983. Man. Dept. Nat. Res. Fish. Br. MS Report No. 84-25, 70pp.
1986	Derksen, A.J. 1986. Ecological Monitoring - Fisheries 1985 Progress Report. Man. Dept. Nat. Res. Fish. Br. April 9, 1986. 43.pp.
	Kirton, J.A.W. 1986. Fish population data from Rat, Karsakuwigamak, and West West and Central Mynarski lakes, 1984. Man. Dept. Nat. Res. Fish. Br. MS Report No. 86-03, 48pp.
	_____1986. Fish population data from Split and Stephens lakes, 1984. Man. Dept. Nat. Res. Fish. Br. MS Report No. 86-04, 61pp.
	Green, D.J. 1986. Summary of Fish mercury data collected from lakes on the Rat-Burntwood and Nelson River systems, 1983-1985. Man. Dept. Nat. Res. MS Report No. 86-06, 359 pp.
	Mohr, L.C. and J.A.W. Kirton. 1986. Fish population data from Sipiwesk and Cross lakes, 1985. Man. Dept. Nat. Res. Fish. Br. MS Report No. 86-28, 83pp.
1987	Sopuck, R. D. 1987. A study of lake sturgeon (Acipenser fulvescens) in the Sipiwesk Lake area of the Nelson River, Manitoba, 1976-1978. Man. Dept. Nat. Res., Fish. Br. MS Report No. 87-2, 59pp.
	Hagenson, I. 1987. Fish population data from Rat and Split lakes, 1985. Man. Dept. Nat. Res. Fish. Br. MS Report No. 87-04, 59pp.
	Kirton, J.A.W. 1987. Fish population data from Macheewin, Osik, Footprint and Threepoint lakes, 1984. Man. Dept. Nat. Res. Fish. Br. MS Report No. 87-06, 78pp.

Appendix 1, continued.

Year	Title
1987	Green, D.J. 1987. Summary of fish population data from Rat and Threepoint lakes, 1986. Man. Dept. Nat. Res. Fish. Br. MS. Report No. 87-07, 47pp.
	Kirton, J.A.W. and L.C. Mohr. 1987. Fish population data from Wuskwatim and Apussigamasi lakes, 1984. Man. Dept. Nat. Res. Fish. Br. MS Report No. 87-08, 44pp.
	Sopuck, R.D. 1987. An analysis of changes in the Pipestone Lake fish community from 1980 to 1986. Man. Dept. Nat. Res., Fish. Br. MS Report No. 87-11, 59pp & Appendices.
	Livingston, L. 1987. A checklist of phytoplankton genera for Nelson River and Rat-Burntwood lakes, 1980, 1981 and 1986. Man. Dept. Nat. Res. Fish. Br. MS Report No. 87-14, 20pp.
	Hagenson, I. 1987. Fish population data from Split and Stephens lakes, 1986. Man. Dept. Nat. Res. Fish. Br. MS Report No. 87-26, 59pp.
	Green, D.J. 1987. Summary of fish population data collected from eight lakes on the Rat-Burntwood River System, 1985. Man. Dept. Nat. Res. Fish. Br. MS Report No. 87-27, 130pp.
	Mohr, L. 1987. Fish population data from Sipiwesk and Cross lakes, 1986. Man. Dept. Nat. Res. Fish. Br. MS Report No. 87-28, 87pp.
	Anonymous. 1987. A manual for ecological monitoring - data collection procedures. Man. Dept. Nat. Res. Fish. Br. June, 1987.
	Mohr, L. and Livingston, L. 1987. Ecological monitoring zooplankton analysis methodology for 1986/87. Man. Dept. Nat. Res. Fish. Br. June, 1987.
	Derksen, A.J. and D.J. Green. Total mercury concentrations in large fishes from lakes on the Churchill River Diversion and Nelson River. Canada-Manitoba Agreement on the Study and Monitoring of Mercury in Churchill River Diversion. Tech. Appendices to Summary Report Volume 4, paper no. 17.

Appendix 1, continued.

Year	Title
1988	Derksen, A.J. et.al. 1988. Ecological Monitoring - Fisheries 1986 Progress Report. Man. Dept. Nat. Res. Fish. Br. March, 1988.
	Livingston, L. 1988. Summary of phytoplankton data for the Nelson River and Rat-Burntwood lakes, 1987. Man. Dept. Nat. Res. Fish. Br. MS Report No. 88-04, 164pp.
	Green, D.J. 1988. Summary of fish population data from Rat and Threepoint lakes, 1987. Man. Dept. Nat. Res. Fish. Br. MS. Report No. 88-11, 55pp.
	_____, 1988. Summary of fish population data from Sipiwesk and Cross lakes, 1987. Man. Dept. Nat. Res. Fish. Br. MS Report No. 88-12, 90pp.
	Patalas, J.W. 1988. The effects of commercial fishing on lake sturgeon (Acipenser fulvescens) populations in the Sipiwesk Lake area of the Nelson River, Manitoba, 1987-1988. Man. Dept. Nat. Res. Fish. Br. MS Report No. 88-14, 38pp.
	Hagenson, I. 1988. Fish population data from Split and Stephens lakes, 1987. Man. Dept. Nat. Res. Fish. Br. MS Report No. 88-15, 66pp.
1989	Green, D.J. 1989. Summary of fish population data from Sipiwesk and Cross lakes, 1988. Man. Dept. Nat. Res. Fish. Br. MS. Report No. 89-11, 91pp.
	Livingston, L.R. 1989. Summary of phytoplankton data for the Nelson River and Rat-Burntwood lakes, 1988. Man. Dept. Nat. Res. Fish. Br. MS Report No. 89-07, 81pp.
	Green, D.J, 1989. Summary of fish population data from Rat and Threepoint lakes, 1988. Man. Dept. Nat. Res. Fish. Br. MS Report No. 89-13, 69pp.
	Cherepak, B. C. 1989. The post-flood morphometry and bathymetry of Rat and Threepoint lakes, 1988. Man. Dept. Nat. Res. Fish. Br. MS Report No. 89-14.

Appendix 1, continued.

Year	Title
1989	Ramsey, D. J. et al. 1989. Evolution of limnological conditions in lakes of the Nelson and Rat-Burntwood river systems after Churchill River diversion and Lake Winnipeg regulation: I. An Overview. Man. Dept. Nat. Res. Fish. Br. MS Report No. 89-15.
	Hagenson, I. 1989. Fish population data from Split and Stephens lakes, 1988. Man. Dept. Nat. Res. Fish. Br. MS Report No. 89-16.